REPORT OF RESEARCH AND TECHNOLOGIC WORK ON COAL AND RELATED INVESTIGATIONS JULY 1, 1952, TO DECEMBER 31, 1953

BY R. L. BROWN AND E. P. CARMAN

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R. L. Brown[1] and E. P. Carman[2]

CONTENTS

Page

Introduction and summary 1
Acknowledgments 4
Origin, composition, and properties of coal and related materials 6
  Inspection, sampling and analysis 6
    Analysis of miscellaneous materials 7
  Constitution, properties, and analytical methods 8
    International classification and analysis of coal .. 8
    Moisture-holding capacity of coal 10
    Small-scale laboratory coking tests 11
    Electron and X-ray diffraction studies of iron catalysts for Fischer-Tropsch process 13
    Petrographic analysis of coal 13
    Sulfur in lignite 14
Coal mining 14
  Study of known recoverable reserves of coking coal 14
    Knott County, Ky. 14
    McDowell County, W. Va. 17
    Wyoming County, W. Va. 17
    Allegany County, Md. 18
    Somerset County, Pa. 18
    Allegheny County, Pa. 19
    Letcher County, Ky. 19
    Tennessee 20

  Coal investigations: Alaska and United States 20
    Alaska 20

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CONTENTS (Con.)

	Page
Tennessee	21
North Carolina	21
Foreign coal investigations and technical assistance	21
Brazil	22
Colombia	22
Philippine Islands	22
Afghanistan	22
India	23
Pakistan	23
Natural gas storage in coal-mining areas	23
Mining methods and practices	24
Trends in anthracite mining	24
Anthracite mechanical mining research	24
Mechanization at bituminous-coal and lignite mines	30
Bituminous coal-mining studies	30
Roof-fall fatalities in coal mines	32
Haulage fatalities in coal mines	35
Analysis of coal-mine accident data	35
Roof control	36
Mine-timber preservation by collar method	37
Anthracite flood prevention	37
Mine air and dust	37
Coal-mine ventilation	39
Preparation of coal	40
Trends in mechanical cleaning of bituminous coal	40
Coal washing	40
Alaska	40
Korea	40
Arkansas	42
Cleaning and dewatering fine coal	42
Dense-medium processes	43
Preparation characteristics of coking coals	45
Pike County, Ky.	45
Floyd County, Ky.	45
Jefferson County, Pa.	46
Knott County, Ky.	46
Coal for electrodes	47
Preparation of lignite	47
Drying low-rank coals	48
Briquetting low-temperature char	50
Utilization of coal and other fuels for combustion	51
Combustion of anthracite	51
Anthracite Laboratory investigations	51
The Anthratube	51
Fuel engineering service	51
Factors affecting heat absorption in furnaces	57
Utilization of low-grade coals	58
Disposal of radioactive wastes by incineration	58
Tests of Army stoves and cookers	59
Other investigations related to fuel utilization	59
Tests of a heat pump for domestic heating and cooling	59
Flow properties of fine powders	61

CONTENTS (Con.)

Page

Germanium from coal 61
Boiler feed-water conditioning 61
Boiler water research 62
Air and stream pollution 63
    Mine-refuse fires 63
    Smoke abatement 64
    Air pollution 64
    Stream pollution 65
Survey and study of carbonizing behavior of coals and blends . 66
    Survey of carbonizing properties of American coals 66
        Pennsylvania coals 66
        West Virginia coals 68
        Kentucky coals 69
        Tennessee coals 69
        Virginia coals 70
        Wyoming coals 71
    Coal expansion during carbonization 71
        Expansion of low-volatile coals 71
        Effect of coal cleaning on expansion 71
        Effect of blending on expansion 72
    Analysis of carbonization data and study of precision of coke tests 72
    Study of the mechanism and kinetics of carbonization 74
    Entrained and fluidized low-temperature carbonization ... 74
Gasification of coal and lignite 77
    Anthracite for making producer gas 77
    Gasification of pulverized coal with oxygen and steam ... 78
    Gasification of Rhode Island meta-anthracite for production of mineral wool 78
    Gasification of lignite...................................... 80
    Underground gasification 85
Research on production of synthesis gas 86
    Kinetics of gasification reactions 86
    Gasification of coal 86
    Purification of synthesis gas 89
Synthetic liquid fuels by gas synthesis 89
    Properties of iron catalysts 89
    Synthesis with iron catalysts 92
    Feed-rate control 94
    Gas synthesis demonstration plant 94
    The Oxo reaction 94
Synthetic liquid fuels by coal hydrogenation 95
    Equipment for hydrogenation of coal 95
    Hydrogenation of coal and shale oil 96
    Characterization of coal and products from hydrogenation. 97
    Bibliography of pressure hydrogenation 99
Analytical techniques for characterizing products from gas synthesis and coal hydrogenation 99
Synthetic liquid fuels publications 100

ILLUSTRATIONS

Fig. Page

1. Proposal for an international scientific system of hard-coal classification by rank 9
2. Status of coking-coal-reserves investigations in Pennsylvania, West Virginia, Kentucky, and Maryland as of December 31, 1953 15
3. Status of coking-coal-reserves investigations in Tennessee as of December 31, 1953 16
4. Induced caving applied to steeply pitching anthracite beds 25
5. Initial installation of the Brieden pneumatic packing machine 27
6. Proposed telescopic steel shield 28
7. Underground installation of load cells and recording device 29
8. Progress of longhole retreat mining 31
9. Steel props and I-beam caps supporting roof at face 33
10. Plan of completed experimental panel 34
11. Sketch map of South Korea, showing location of mining fields investigated 41
12. Dense-medium pilot plant at Seattle station, Bureau of Mines 44
13. Pilot plant for drying and carbonizing noncoking coal .. 49
14. Anthracite Research Laboratory, experimental boiler room 52
15. View of front and side of Anthratube 53
16. Corrosion rate in Harding Street Station air preheater of various materials relative to that of Cor-Ten steel 55
17. Corrosion rate in Harding Street Station air preheater of various materials relative to that of Cor-Ten steel 56
18. Schematic diagram of model incinerator 60
19. Expansion of coal blends 73
20. Pilot plant for drying and carbonizing fine coal 75
21. Integrated drying and carbonizing plant, Denver, Colo... 76
22. Enthalpy balance chart 79
23. Slagging producer 81
24. Flow diagram of externally heated annular retort process for gasifying lignite, Bureau of Mines, Grand Forks, N. Dak.. 82
25. Heat distribution during gasification of lignite in an externally heated retort at various hydrogen-carbon monoxide ratios, Bureau of Mines, Grand Forks, N. Dak. 84
26. Pilot-plant flowsheet for gasifier No. 3 87
27. Coal-feeder flowsheet 88
28. Magnetic balance for thermomagnetic analysis of catalysts 91
29. Pilot plant for removing carbon dioxide from synthesis gas 93
30. Small-angle X-ray diffraction camera 98
31. Apparatus for measuring action of radioactive samples ... 101

INTRODUCTION AND SUMMARY

This report is the 18th in a series summarizing Bureau of Mines research and technologic work on coal and related investigations. The previous 17 reports have covered fiscal years, but this report covers not only the fiscal year from July 1, 1952, to June 30, 1953, but also July through December 1953, to bring the report to a calendar-year basis. Most of the material in this report relates to publications issued during the reporting period. Some work is mentioned briefly on which publications have not yet been issued or on which data are not expected to be published, for security or other reasons, and in a few instances publications issued before the reporting period but not included in the previous report are mentioned.3/ Further details on the published work described herein may be found by referring to the publications cited in the footnotes.

During the reporting period, the Bureau directed its research and technologic work on coal toward developing and encouraging increased conservation and more efficient use of our mineral fuel resources through more efficient and safer mining methods and improved methods of preparing and utilizing these fuels. Some significant advances, particularly in coal-mine safety, mining methods, and development and utilization of low-rank coals have been made.

The Bureau of Mines has contributed to coal-technology investigations in various parts of the world, primarily as a result of its participation in the United States Government Point 4 program of technical assistance. Bureau coal technologists gave such assistance in Brazil, Colombia, Republic of the Philippines, Afghanistan, Pakistan, Formosa, and India, seeking to improve economic conditions in the underdeveloped areas of the world by encouraging wider and more efficient use of their natural resources. In addition to field projects, foreign coals were tested in Bureau laboratories. Bureau technologists have given technical assistance and made check tests with other laboratories in this country and abroad in connection with developing international systems for classifying and analyzing coals. Foreign technologists have been trained abroad and in the Bureau's laboratories in this country to carry on the work when United States participation is terminated. These activities have been conducted at the request of the governments of the various countries and the newly formed Foreign Operations Administration and its predecessor, the Technical Cooperation Administration of the United States Department of State.

The technical coal-analysis service and fuel-burning consulting activities of the Bureau for other Government agencies were continued to aid these agencies in purchasing and obtaining fuel deliveries best adapted to the particular installations and in accordance with specifications. This work was supplemented by: Petrographic,

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3/ Brown, R. L., and Ode, W. H., Annual Report of Research and Technologic Work on Coal and Related Investigations, Fiscal Year 1952: Bureau of Mines Inf. Circ. 7663, 1953, 67 pp.

studies of coals; research on moisture-holding capacity of low-rank coals; small-scale laboratory coking tests and determination of low-temperature carbonization yields and products; and use of the electron microscope to study coal structure and the characteristics of Fischer-Tropsch catalysts.

Publication of seven county reports of known recoverable reserves of coking coal in Appalachian coal fields in Pennsylvania, Maryland, West Virginia, and eastern Kentucky and substantial progress in the investigation in Tennessee, provided information on potential new sources of metallurgical coke. Studies of the preparation and carbonizing characteristics of coals from these areas were continued, and it was decided to combine all three phases of the investigation - reserves, preparation characteristics, and analysis and carbonizing properties - in the county reports for Tennessee.

Full mechanization of coal mines proceeded rapidly during this period, improving efficiency and safety of coal mining. After the Bureau's cooperative initial trials of the coal planer in a bed of friable Pocahontas coal in West Virginia, reported briefly in the previous technologic review report and in more detail in this one, the planer was moved to a new mine where more extensive reserves are available. Two more companies purchased planers for trials under different conditions of bed thickness and coal friability. A Bureau study of the increasingly popular, American-made continuous miners was continued to develop data for a later publication on operation of these machines under varying conditions. New methods of recovering anthracite from thick, steeply pitching beds were investigated, and the studies on causes and remedies for various types of coal-mine accidents were continued. The Federal Coal-Mine Safety Act became effective, and record lows in coal-mining accidents were reported as the Bureau continued its regular and check inspection of coal mines.

Problems involved in washing coals of Alaska, Korea, and Arkansas were studied to provide fuels to meet specific demands in those areas, and research on close-gravity separation of difficult-to-clean coals was conducted in two heavy-medium pilot plants.

As coal is being produced with a larger proportion of finer sizes, considerable attention in the Bureau was devoted to improving methods of dewatering and drying fine sizes of coal and recovering fines from washery sludges to avoid stream pollution. Fluidized drying of low-rank coal advanced to large-scale commercial application, fluidized-dried lignite being used as thermal power-plant fuel at a Texas installation not far from the source of much of the Texas oil and natural gas. Design of fluidized carbonziers to follow the drying stage and produce power-plant char and low-temperature tar and chemical products was completed, and construction of the first unit was well advanced. A study of the trends in power production and use of fuels in 11 Western States indicated that the smaller and more specialized heating loads will tend to go to natural gas and oil, whereas coal will probably be used in larger installations, such as utility-type, electric power plants. If indicated trends materialize, by 1975 coal production will have increased to 4 times the 1953 rate in this area.

Possible new uses for anthracite were studied. The Bureau continued its cooperative work on the study of factors affecting heat release and absorption in large, utility-type power boilers. Design factors were developed for incinerators for burning radioactive wastes and for small liquid-fuel-fired Army stoves and cookers. One very effective solution for controlling or preventing fires in mine-waste piles was found, and the occurrence and possibilities of recovery of germanium from furnace flue dusts were studied. The Bureau's research and service work on boiler water and water side corrosion and deposition were continued, and savings to the Government from recommendations made on the basis of this work were estimated to be at least equal to the appropriations for fiscal year 1953 for the entire Bureau of Mines.

Two special studies were made of heating and air-conditioning equipment suitable for use in Government housing and small offices and stations. One study was on operation of the anthracite-fired Anthratube for domestic and small industrial-commercial space and hot-water heating, and the other was on one of the early commercial packaged heat-pump installations.

Recommendations based on Bureau research and studies were made in connection with problems relating to smoke abatement and air and stream pollution in various areas.

Studies of coal carbonization included testing carbonizing properties, yields of gas and chemical products, and expanding or contracting properties of coals where investigations of known recoverable reserves have shown substantial remaining reserves. Carbonizing tests were made in the pilot-scale Tuscaloosa test oven simulating commercial slot-type ovens in materials of construction and oven width. These tests gave operating data, which were included in a publication describing the oven. Correlation of carbonizing-test data from many years' operation of the Bureau of Mines-American Gas Association (BM-AGA) pilot-scale retorts at Pittsburgh was begun, and the preliminary results of a fundamental investigation of the basic factors and causes involved in the coking of coal were described.

A cooperative research program to determine the practicability of using Rhode Island meta-anthracite as fuel and rock source for making rock wool showed that the major technical problems had been solved. It was concluded from another study of gasifying high-ash rejects from Pennsylvania anthracite (bone coal and breaker wastes) that commercial producers would have to be modified in design to handle the large volumes of ash.

In the tests of underground gasification at Gorgas, Ala., underground mining was eliminated by electro-linking, and the properties of the gas were varied within wide limits by changing the conditions of gasification.

To produce synthesis gas, pilot-plant tests were made on gasification of coal with oxygen under pressure. Comparatively small heat losses were observed, operation under slagging conditions was possible, and erosion of refractory lining was under control.

Research on the production of synthetic liquid fuels was continued with studies of gas synthesis; improvement of catalysts; hydrogenation of coal; and separation, synthesis, and characterization of products obtained in these processes. Details of progress during 1952 may be found in the Annual Report of the Secretary of the Interior for 1952 on synthetic liquid fuels.4/5/

4/ Bureau of Mines, Synthetic Liquid Fuels. Annual Report of the Secretary of the Interior for 1952. Part I. - Oil From Coal: Rept. of Investigations 4942, 1953, 85 pp.

5/ Bureau of Mines, Synthetic Liquid Fuels. Annual Report of the Secretary of the Interior for 1952. Part II. - Oil from Oil Shale: Rept. of Investigations 4943, 1953, 70 pp.

During the reporting period the Synthetic Liquid Fuels demonstration plant at Louisiana, Mo., and the underground gasification project at Gorgas, Ala., were shut down.

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The following organizations, institutions, and companies have cooperated with the Bureau by helping to finance research projects or arranging for or assisting in conducting research and technologic work on coal. Their cooperation is hereby acknowledged.

Air Preheater Corp.
Air Products, Inc.
Air Reduction Co.
Alaska Territorial Department of Mines
Aluminum Company of America
American Society of Mechanical Engineers
Anthracite Institute
Atomic Energy Commission
Autoclave Engineers, Inc.
Babcock & Wilcox Co.
Banco de Mexico, D. F.
Bituminous Coal Research, Inc.
Boeing Airplane Co.
Carbide & Carbon Chemicals Co.
Cebu Portland Cement Co., Manila, Philippine Islands
Coal Control Commission of the Government of China, Taipei, Formosa
Combustion Engineering - Superheater, Inc.
Companhia Siderurgica Nacional, Rio de Janeiro, Brazil
Compania Carbonifera de Sabinas, S. A.
Conselho de Carvao Nacional, Rio de Janeiro, Brazil
Corporacion Carbonera Colombiana, Cali, Colombia
Dakota Briquets and Tar Products, Inc.
Damodar Valley Development Corp., Bermo, India
Department of Defense, Air Force
Department of Defense, Army, Chemical Corps
Department of Defense, Army, Office of Quartermaster General
Department of Defense, Army, Signal Corps
Department of Defense, Navy, Bureau of Yards and Docks
Department of the Interior, Secretary's Office (water purification)
Departamento Nacional da Producao Mineral, Rio de Janeiro
Division of Geology, State of Tennessee
Eastern Gas & Fuel Associates
Ford Motor Co.
General American Transportation Co.
Glen Alden Coal Co.
M. A. Hanna Co., Susquehanna Collieries Division
Hazelton Brick Co.
Hudson Coal Co.
Illinois Geological Survey
Instituto de Fomento Industrial, Bogota, Colombia

Instituto Mexicano de Investigaciones Tecnoligicas, Mexico, D. F.
Instituto Nacional para la Investigacion de Recursos Minerales, Mexico, D. F.
International Joint Commission
International Nickel Co.
Island Creek Coal Co.
Kemmerer Coal Co.
Koppers Co.
Lehigh Navigation Coal Co.
Lehigh Valley Coal Co.
Louisiana Power & Light Co.
Missouri Basin Field Committee (Regions IV and V)
National Power Co., Manila
New England-New York Interagency Commission
Northwestern Improvement Co.
C. M. Otto & Son
Pakistan Industrial Development Corp., Karachi, Pakistan
Pennsylvania Crusher Co.
Philadelphia & Reading Coal & Iron Co.
Philippine Bureau of Mines, Manila, P. I.
Pine Township Coal Co.
Pittsburgh Consolidation Coal Co.
Republic Steel Corp.
Roslyn-Cascade Coal Co.
Royal Afghan Ministry of Mines, Kabul, Afghanistan
Tennessee Valley Authority
Texas Power & Light Co.
Truax-Traer Coal Co.
U. S. Foreign Operations Administration in Manila, Taipei, (Formosa), Rio de Janeiro, Mexico, D. F., Bogota, New Delhi, Kabul, Karachi, (and Brussels, Belgium), Bangkok
Federal Geological Survey, for work in United States and Alaska
Federal Geological Survey in Manila, P. I.; Belo Horizonte, Mexico, D. F.; Bogota, Columbia.
University of Alabama
University of Alaska School of Mines
University of North Dakota
University of Washington
University of West Virginia
Wellman Engineering Co.
Westinghouse Electric Corp.
J. G. White Engineering Co., Taipei and Indonesia
Wright Air Development Center

In addition, many coal companies and landowners provided information and data from their files in connection with the estimation of known minable coking-coal reserves, their preparation and carbonizing properties. In many instances they also aided the Bureau engineers in evaluating and tabulating such data without the necessity of formal cooperative agreements. Their cooperation and aid materially assisted progress of the studies and are acknowledged.

ORIGIN, COMPOSITION, AND PROPERTIES OF COAL AND RELATED MATERIALS

Inspection, Sampling, and Analysis

From July 1952 to December 1953, inclusive, coal was produced over demand, and Federal agencies had no difficulty in obtaining bids to cover their requirements. All agencies except the Post Office Department purchased on a guaranteed-analysis basis, including penalties for delivery of substandard coal. The Department of the Navy, purchasing coal for the Armed Services, was the largest Federal coal-purchasing agent. Other departments requiring substantial amounts purchased their own coal, but the General Services Administration purchased for some agencies whose requirements were small. Contracting for coal for the fiscal year 1954 began in February 1953 and continued through July 1953.

Coal requirements of Federal agencies for the period, excepting the Atomic Energy Commission and coal purchased for export, were estimated at approximately 7,000,000 tons. Requests from Federal agencies for analyses for use in evaluating bids continued at about the same rate as the previous year, which was the largest in history, because of the large numbers of bids and strict adherence to specification requirements on eliminating mines on which there were no Bureau of Mines analysis records. In addition, recommendations were made for awards of contracts for some agencies.

In the 18 months of the reporting period, proximate or ultimate and heating-value analyses were reported on 15,667 samples; ash-fusing-temperature determinations were reported on 4,123 samples; free-swelling index on 1,184 samples; and Hardgrove grindability on 367 samples from purchases of coal and tipple inspections taken in connection with Government coal purchases. A total of 1,329 tipple samples collected at 488 mines in 20 States and Alaska was reported; 83 face samples were collected at 69 mines.

On request of the Department of the Army, 94 cargoes (approximately 700,000 gross tons) were sampled at Tidewater piers by Bureau of Mines Regions II, IV, and VIII, the Washington Office acting as liaison between the Army and the Bureau of Mines and coordinating the work of the regions. At the request of the Marine Corps, sampling methods were investigated at the Marine Corps Schools, Quantico, Va., and personnel was instructed in proper sampling procedures.

To meet the increasing number of demands for more up-to-date coal analyses of individual mines, a new series of annual coal-analyses publications[6/][7/][8/] was begun. These publications list the mine location and bed mined and include chemical analyses, calorific values, classifications by rank, agglomerating indexes, ash-softening temperatures, free-swelling indexes, and Hardgrove grindability indexes. A comprehensive bulletin[9/] on coals of Ohio included geological features, methods of mining,

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[6/] Snyder, N. H., and Aresco, S. J., Analyses of Tipple and Delivered Samples of Coal (Collected During the Fiscal Years 1948-50, Incl.): Bureau of Mines Bull. 516, 1953, 133 pp.

[7/] Aresco, S. J., and Haller, C. P., Analyses of Tipple and Delivered Samples of Coal (Collected During the Fiscal Year 1951): Bureau of Mines Rept. of Investigations 4934, 1953, 93 pp.

[8/] Aresco, S. J., and Haller, C. P., Analyses of Tipple and Delivered Samples of Coal (Collected During the Fiscal Year 1952): Bureau of Mines Rept. of Investigations 4972, 1953, 84 pp.

[9/] Fieldner, A. C., Taylor, Dorothy A , Toenges, A. L., Crentz, W. L., Fraser, T., Young, W. H., Anderson, R. L., Snyder, N. H., Cooper, H. M., Abernethy, R. F., and Hartner, F. E., Analyses of Ohio Coals: Bureau of Mines Bull. 499, 1952, 93 pp.

preparation, production, distribution, use, analyses, specific gravities, and sulfur forms.

To answer many requests and to supply a comprehensive file on the analyses of foreign coals, a bulletin[10] was prepared listing coal analyses from all foreign coal fields for which records were available. The analysis table was arranged on the basis of continent, country, geographical subdivision, and region or mine. Six continental maps showing fields were included, with tabulations of world production of coal and lignite and world resources of brown coal and lignite.

At the request of military procurement officers in Alaska, coal-sampling schools were conducted again at the principal Air Force and Army bases in the Anchorage and Fairbanks areas. Advice and assistance were given on coal-bidding procedure, specifications, delivery schedules, and storage problems.

A coal-analysis laboratory has been reestablished in Alaska in limited space made available in the new Territorial Department of Mines building at Anchorage; equipment is being standardized. The laboratory will facilitate making analyses to aid in control and settlement of coal shipments to military and other Government establishments in Alaska.

During the reporting period proximate, sulfur, heating-value, ultimate, and other analyses were made of 44,076 samples of coal, coke, char, tar, residue, coal-mine dust, and related materials. Sampling for Government purchases and inspections of tipples provided 17,276 samples, 76 percent of the requests for which came from branches of the Department of Defense. The Bureau of Mines and other Government organizations submitted or requested 6,786 samples in connection with research on and use of coals, and the Coal-Mine Inspection Branch of the Bureau's Accident-Prevention and Health Division submitted 20,014 samples from 3,675 inspections of coal mines in 19 States, made to determine safety conditions in coal mines. Analyses of coal were given to the Bituminous Coal Mining Branch to use in preparing seven reports on coking-coal reserves. The samples analyzed during the reporting period required 517,502 chemical and physical tests to provide the information requested with samples submitted.

Analysis of Miscellaneous Materials

Chemical analyses and tests were made of 154 samples of miscellaneous materials in connection with various investigations of coal utilization, mining, and accident prevention. These samples included inert dusts proposed for rock-dusting coal mines, coal ashes and slags, ash from coal refuse, and perlite, an aluminum silicate mineral used in manufacturing heat-insulating material and lightweight aggregate for concrete and plaster.

In connection with an investigation by the Health Branch of the properties of perlite and safety conditions in this industry, samples of crude perlite from 10 mines in Arizona, California, Colorado, Nevada, New Mexico, and Utah were analyzed. Total silica was determined in 46 samples collected from various stages of processing in several plants. Comparison of analyses of crude perlite from the 10 different sources showed very little variation in chemical composition.

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[10] Morgan, R. E., and Barkley, J. F., Analyses of Foreign Coals: Bureau of Mines Bull. 512, 1952, 34 pp.

Constitution, Properties, and Analytical Methods

International Classification and Analysis of Coal

The Bureau of Mines equipment and procedure for coal volatile-matter determination was demonstrated to the International Standards Organization Working Group, in London, England, in connection with cooperative work with this group to establish international standards for analyzing coal.

The Bureau of Mines cooperated with the Classification Working Party of the Coal Committee, Economic Commission for Europe, in formulating international systems of coal classification by designating a delegate who has attended 6 of the 8 regular sessions of this international group since the organizational meeting at Geneva, Switzerland, in 1949. Many European countries are participating in this work, and at the eighth session held in Geneva, Switzerland, November 1953, delegates and technical experts attended from Austria, Belgium, Denmark, Luxembourg, Sweden, France, Italy, the Netherlands, Poland, the United Kingdom, the United States of America, the Western Zones of Germany, Yugoslavia, and, for the first time, a group from the Eastern Zone of Germany.

At the fifth session of the Classification Working Party, Geneva, July 1952, agreement was reached on a proposed international scientific system of hard coal classification by rank, that is, according to differences in their degree of coalification in the natural series from brown coal to anthracite. The term "hard coal", according to European usage, refers to all coals higher in rank than lignite and brown coal. The classification system agreed upon is shown in figure 1. According to this scheme, coals with volatile matter up to and including 30 percent are classified according to their volatile-matter content on a dry, ash-free basis, and coals above 30 percent volatile matter are classified according to their calorific value on a moist, ash-free basis. "Moist" refers to the coal containing its natural bed moisture. By using these 2 parameters, coals are divided into 10 classes and given code numbers 0-9. The classes are then subdivided into four groups, according to caking properties, as determined by either the free-swelling index or the Roga index, and these are assigned code numbers 0-3. The Gray-King coking index and the Audibert-Arnu dilatometer test are then used as alternative parameters for dividing the groups into subgroups according to coking properties. These subgroups are given code numbers 0-5. Under this system coals are designated by three-digit code numbers, the first numeral giving its rank, the second its caking characteristics, and the third its coking characteristics.

An international system of hard-coal classification for commercial purposes was tentatively agreed upon at the eighth (November 1953) session of the Working Party. This is a simplification of the scientific system arranged to group coals of generally like properties into 10 main groups. The executive secretary, E. C. E., has circulated an invitation to each of the participating countries to give the proposed system of commercial classification a trial over a period of not longer than 2 years, with a view of putting it into general use in the coal trade by the end of 1955.

Information on the occurrence, chemical and physical properties, petrography, and classification of the different varieties of lignites[11] of the United States was prepared for the Classification Working Party in connection with its work in formulating a classification scheme for lignites and brown coals that are not included in the hard-coal classification systems.

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[11] Selvig, W. A., Properties of Lignites of the United States: Fuel, vol. 32, No. 1, January, 1953, pp. 28-35.

GROUPS (determined by caking properties)			CODE NUMBERS										SUBGROUPS (determined by coking properties)		
GROUP NUMBER	ALTERNATIVE GROUP PARAMETERS		The first figure of the code number indicates the class of the coal, determined by volatile matter content up to 30% V.M. and by calorific parameter above 30% V.M. The second figure indicates the group of coal, determined by caking properties. The third figure indicates the subgroup, determined by coking properties.										SUBGROUP NUMBER	ALTERNATIVE SUBGROUP PARAMETERS	
	Free Swelling Index	Roga Index												Dilatometer	Gray-King
3	> 4	> 45					435	535	635	735			5	> 140	> G 8
						334	434	534	634	734			4	50 - 140	G 5 - G 8
						333	433	533	633	733			3	0 - 50	G 1 - G 4
						332	432	532	632	732	832		2	⩽ 0	E - G
2	2.5 - 4	20 - 45				323	423	523	623	723	823		3	0 - 50	G 1 - G 4
						322	422	522	622	722	822		2	⩽ 0	E - G
						321	421	521	621	721	821		1	Contraction only	B - D
1	1 - 2	5 - 20			212	312	412	512	612	712	812		2	⩽ 0	E - G
					211	311	411	511	611	711	811		1	Contraction only	B - D
0	N. A.	0 - 5	000	100 A B	200	300	400	500	600	700	800	900	0	Nonsoftening	A
CLASS NUMBER			0	1	2	3	4	5	6	7	8	9	As an indication, the following classes have an approximate volatile matter content of: Class 5 30-36% volatile matter 6 30-41% " " 7 33-44% " " 8 35-50% " " 9 42-50% " "		
CLASS PARAMETERS	Volatile Matter (d.a.f.)		0 - 3	> 3 - 10 A: > 3 - 6.5 B: > 6.5 - 10	> 10 - 14	> 14 - 20	> 20 - 30	> 30	> 30	> 30	> 30	> 30			
	Calorific parameter: (gross calorific value on moist, ash-free basis) (30° C, 97% humidity) kcal/kg.		—	—	—	—	—	> 8450	8450-7750	7750-7200	7200-6100	< 6100			

CLASSES
(Determined by volatile matter up to 30% V.M. and by calorific parameter above 30% V.M.

NOTE: The caking and coking properties should be determined on coal samples with an ash content not greater than 10%. If the ash content of the samples is above 10%, it should be reduced by flotation or any other appropriate process.

Figure 1. - Proposal for an international scientific system of hard-coal classification by rank.

Two general types of lignite occur in the United States and are recognizable by physical appearance and petrographic components. The more common kind is designated as xyloid or woody type, and the other is designated as the attrital or earthy-type lignite. One variety of this latter type, designated as canneloid attrital lignite, is made up largely of cuticular matter, spores, pollen, resin, and waxes. This variety has been mined in California and processed to recover wax.

The American standard boundary between lignites and subbituminous coals in this country is 8,300 B.t.u. on the moist, mineral-matter-free basis. To obtain data required by the Classification Working Party for establishing significant boundary lines for the international classification of lignites and brown coals, laboratories of different countries are cooperating in making analyses of typical samples of these coals from Europe and from the United States. The Bureau of Mines furnished samples of typical lignites and subbituminous coals of the United States for tests by the other countries and received samples of typical lignites and brown coal from Belgium, Western Germany, Greece, Italy, Poland, and Yugoslavia.

The Classification Working Party has tentatively proposed that 5,000 calories (9,000 B.t.u.) on the moist, ash-free basis be the parameter for separating lignites and brown coals from hard coals and that 30 percent humic acid on the dry, ash-free basis be used to differentiate between lignites and brown coals, the brown-coal class being over 30 percent humic acids, as determined by a prescribed method. Further work is in progress to establish the validity of these proposed parameters.

Moisture-Holding Capacity of Coal

According to the Standard Specifications for Classification of Coals by Rank, American Society for Testing Materials, high-volatile bituminous coals, subbituminous coals, and lignites are classified on the basis of calorific value on the moist, mineral-matter-free basis, that is, coal containing its natural-bed moisture but not including visible water on the surface of the coal. It is assumed, for practical purposes, that the moisture content of the coal when brought to a standard condition of moisture equilibrium in an atmosphere of 97 percent relative humidity and 30° C. represents the bed moisture of the coal as it normally occurs in the ground. The A.S.T.M. specifications provide that this moisture condition shall be obtained by bringing the coal to a standard condition of moisture equilibrium at 30° C. in a vacuum desiccator containing a saturated solution of potassium sulfate (97 percent relative humidity). The specifications do not mention bringing partly air dried samples to their natural bed-moisture condition.

Tests[12] were made to determine if partly air dried coals could be restored to their approximate natural bed-moisture condition by first wetting the coals and then equilibrating them from the wet state. This modification of first wetting the coals was recommended by D. J. W. Kreulen[13] in 1951. Six high-moisture coals tested included a high-volatile C bituminous coal from Illinois, subbituminous B and C coals from Colorado, and three lignites from North Dakota, Texas, and California.

For practical purposes of coal classification it was concluded from the tests that bituminous and subbituminous coals, even though air-dried to relatively low moisture contents, can be restored to virtually their natural bed-moisture condition by equilibrium from the wet state at 97 percent relative humidity and 30° C. With the lignites, however, it was not possible by this method to replace all of the original bed moisture when working with air-dried samples, probably because of shrinkage of pore volume caused by air drying. The lignite samples contained about 35 percent moisture in the freshly mined condition, and when air-dried to 25 percent moisture content the equilibrium moisture values were 0.9 to 3.3 percent lower than the moisture-holding capacity of the fresh coal; when air-dried to 20 percent, results were 1.2 to 3.8 percent lower; and when air-dried to 15 percent, results were 2.2 to 5.4 percent lower.

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[12] Selvig, W. A., and Ode, W. H., Determination of Moisture-Holding Capacity (Bed Moisture) of Coal for Classification by Rank: Bureau of Mines Rept. of Investigations 4968, 1953, 10 pp.

[13] Kreulen, D. J. W., (The Adsorption Water of Coal): Chem. en Pharm. Tech. (Dordrecht)., vol. 7, 1951, pp. 23-24.

In addition to the interest from the viewpoint of establishing classification standards, the need for accurate and convenient methods of determining moisture in low-rank coals is becoming increasingly important because of the activities in low-temperature carbonization of the noncaking coals and production of synthetic liquid fuels and chemicals from such fuels.[14/]

Although the standard method of determining moisture is satisfactory for high-rank coals, many coals, including the lignites of Texas and North Dakota, are highly sensitive to oxidation when dried as specified by this method. The extent of such oxidation is enough to impair the accuracy of the moisture analysis when made by the conventional method. Several methods were investigated to select the most satisfactory means of moisture determination. These included ASTM or Bureau of Mines Method for moisture determination, the Schoch oil-dehydration method, the vacuum-oven method, and the xylol-distillation method.

A comparison of the various methods indicated that the xylol- and the Schoch oil-dehydration methods gave the best results. Each of these yielded higher moisture contents than the other methods studied, since they prevented oxidation of the low-rank fuels during the determination. The xylol method was preferred over the Schoch oil-dehydration method because it is operated at a lower temperature, requires considerably less observation, involves small amounts of samples, and requires no agitation. The accuracy and simplicity of the xylol method indicated that it is particularly suited for the routine or control analysis of high-moisture coals and lignites.

Small-Scale Laboratory Coking Tests

As part of the survey of the gas- and coke-making properties of American coals, small-scale laboratory coking tests made on various coals to assist in evaluating their metallurgical coke-making properties, included the Fischer-Schrader low-temperature carbonization assay at 500° C. and the Bureau of Mines agglutinating-value test. The assay furnished data on low temperature yields of coke, gas, and byproducts, and the agglutinating-value test gave an index of the coking properties.

Results of the Fischer-Schrader assays of low-volatile bituminous coal from the Beckley bed[15/] in McDowell and Wyoming Counties, W. Va., showed that the coal from

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[14/] Goodman, J. B., Gomez, Manuel, and Parry, V. F., Determination of Moisture in Low-Rank Coal: Bureau of Mines Rept. of Investigations 4969, 1953, 20 pp.

[15/] Reynolds, D. A., Davis, J. D., Wolfson, D. E., Naugle, B. W., Brewer, R. E., Birge, G. W., and Frederic, W. H., Carbonizing Properties: West Virginia Coals From the Beckley Bed, Caretta No. 5 Mine, McDowell County, and Glen Rogers No. 2 Mine, Wyoming County: Bureau of Mines Bull. 522, 1953, 27 pp.

McDowell County yielded slightly more coke but less tar, light oil, and gas than the coal from Wyoming County. These small differences are explained by a higher volatile-matter content of the coal from Wyoming County.

Fischer-Schrader low-temperature-carbonization assays of Tennessee coals[16] from the Jellico and the Sewanee bed were published. Because of its much lower volatile matter content, the Sewanee coal (volatile matter, 28.5 percent) yielded more coke and less tar and light oil than the Jellico coal (volatile matter, 37.3 percent). Agglutinating values at the 15:1 ratio of silicon carbide to coal were 5.3 kg. for the Jellico coal and 7.0 kg. for the Sewanee coal. The higher agglutinating value of the Sewanee coal indicates that it is more strongly coking than the Jellico coal.

Results of low-temperature assay tests, in a modified Fischer apparatus, of low-rank coals from the Missouri River Basin[17] have shown that, when carbonized at 500° C. (the temperature yielding maximum tar-plus-light oil yield), approximately 80 percent of the total potential heat in an average North Dakota lignite can be recovered as char, based on the moisture- and ash-free coal. About 10 percent of the total heat is recovered as tar-plus-light oil and 6 percent as gas. With average Wyoming high-volatile bituminous and subbituminous coals, about 78 percent of the total heat can be recovered in the char, on the same basis, whereas 15 percent is in the tar-plus-light oil and 7 percent in the gas.

The ASTM standard method of test for free-swelling index of coal specifies that the coal sample shall be heated in a silica crucible with a gas burner under prescribed temperature conditions. Difficulties have been encountered in attaining the specified temperatures by gas heating as described in the A.S.T.M. method because of differences in composition of gases and gas pressures in different parts of the country. For this reason, investigators have considered the feasibility of electric heating to obtain closer temperature control. Swartzman and Behnke of the Fuel Research Laboratories, Canadian Department of Mines and Technical Surveys, used a 350-watt, electric cone heater and a 15-ml., platinum volatile-matter crucible and reported that coke buttons produced at 650° C. under these conditions were comparable to those obtained by the standard procedure using silica crucibles and gas heating at 820° C. As the Bureau of Mines has standardized on 10-ml., platinum crucibles for determining volatile matter, tests were made to determine if this size crucible could be used for the free-swelling test when using an electric cone heater.[18] Tests with 10-ml., platinum crucibles and the electric heating method showed that:

(1) The free-swelling index could not be estimated visually because the coke buttons obtained did not conform in shape to the profiles specified in the standard method.

(2) Although free-swelling indexes of coals with indexes of 5 or less could be estimated by measuring profile areas or from the volume of coke buttons, these measurements gave unsatisfactory results for highly swelling coals.

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[16] Reynolds, D. A., Davis, J. D., Birge, G. W., Brewer, R. E., Wolfson, D. E., Ode, W. H., and Naugle, B. W., Carbonizing Properties: Tennessee Coals From the Jellico Bed in Campbell County and the Sewanee Bed in Marion County: Bureau of Mines Bull. 523, 1953, 35 pp.

[17] Gomez, Manuel, and Goodman, J. B., Distillation Assays of Missouri River Basin Coals: Bureau of Mines Rept. of Investigations 5009, 1953, 9 pp.

[18] Selvig, W. A., Discussion of paper, "Using Electric Furnaces and Heaters to Determine the Free-Swelling Index of Coal," by E. Swartzman and G. C. Behnke: Min. Eng., vol. 4, No. 11, November 1952, p. 1081.

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(3) The 10-ml., platinum crucible as used by the Bureau for volatile-matter determinations is too small to give free-swelling indexes agreeing satisfactorily with the standard ASTM method.

Electron and X-Ray Diffraction Studies of Iron Catalysts for Fischer-Tropsch Process

A study was made of the application of electron diffraction techniques to fundamental research on the mechanism of the catalytic formation of synthetic oils, gasoline, and chemicals from carbon monoxide and hydrogen.[19] An understanding of the chemical reactions occurring in such processes is important in developing more economical and efficient procedures. Because the beneficial effects of catalysts in chemical processes depend largely on their surface characteristics, a research technique, such as electron diffraction, that reveals the nature of the surface phases more selectively than highly penetrating X-rays should be of considerable value in basic mechanism studies.

The electron and X-ray diffraction patterns of pretreated and used Fischer-Tropsch catalysts, although similar in some respects, do show consistent differences. Of greatest significance is the dominance of magnetite (iron oxide) lines in the electron diffraction patterns of catalysts that had been used in the synthesis, whereas iron carbide lines were prominent in the X-ray patterns. This indicates that a commonly expressed theory that iron carbide is the active catalyst in the Fischer-Tropsch synthesis of liquid fuels is probably incorrect, because the surface layers apparently contain little or no carbide. It may also be inferred that iron oxide, though it may not be the active catalyst phase, apparently has no appreciable deleterious effect on the activity of the catalyst. At present there is no completely satisfactory concept of the exact way in which the various phases of iron contribute to the catalytic effect in the Fischer-Tropsch synthesis.

Petrographic Analysis of Coal

Investigation of the Deep River coal field in North Carolina[20] involved considerable diamond-drill exploratory testing, during the course of which a number of coal samples were submitted for petrographic study. A procedure developed for the microscopic study of granular coal was used to make a special petrographic study of three selected samples of the Deep River cores and of a face sample from the Carolina mine, the only active operation in the field, since the coal beds are badly fractured and faulted, and core samples were recovered in badly broken condition. A column sample was collected from the same mine for thin-section analysis. Samples of the Upper Cumnock coal bed, the most important coal economically, were prepared for microscopic analysis by crushing the fragmented coal into small granules, a majority of which ranged from about 1/10 to 1/50 inch in diameter. It is possible to observe coal granules of this size in relief under the stereoscopic microscope, and using micromanipulators the particles can be oriented in various positions for critical inspection. Separating coal from impurities in a heavy liquid is an important step in the procedure. The float at 1.55 specific gravity was examined under the microscope, and the coal granules were separated into four categories of banded coal on the basis of visual physical differences.

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[19] McCartney, J. T., Hofer, L. J. E., Seligman, Bernard, Lecky, J. A., Peebles, W. C., and Anderson, R. B., Electron and X-Ray Diffraction Studies of Iron Fischer-Tropsch Catalysts: Jour. Phys. Chem., vol. 57, No. 7, October 1953, pp. 730-736.

[20] Toenges, A. L., Turnbull, L. A., Shields, J. J., Haley, W. A., Parks, B. C., and Abernethy, R. F., Coal Deposits in the Deep River Field, Chatham, Lee, and Moore Counties, N.C.: Bureau of Mines Bull. 515, 1952, 41 pp.

Original from THE OHIO STATE UNIVERSITY

As shown in the report, there was marked variation of ash in the banded components. There was no visible mineral matter in the anthra-xylon, whereas the bright attrital coal contained a moderate amount of visible ash-forming mineral matter. The dull attrital coal showed a high concentration of visible mineral matter in keeping with the high ash content of this component, whereas the fusain had ash content about midway between the bright and dull attrital components.

The results of the petrographic investigations of core and mine samples showed that the proportion of banded-coal components in the Upper Cumnock coal varies considerably, both horizontally and laterally, through the bed. Since the banded-coal components had a marked range in ash content, variation in petrographic composition will be reflected in the ash content of the mined coal, but it is indicated from the petrographic studies that a coal product of rather low-ash content could be obtained from this bed by preparation methods utilizing crushing and gravity separation.

Core and column samples of lignite from some of the principal mines in North Dakota have been investigated for petrographic characteristics. The commercially delivered product of these and other mines is also being studied by the recently developed technique for preparing thin sections from representative samples of crushed delivered coal. Preliminary results support the idea that chemical and preparation characteristics can be correlated with petrographic components, as will be discussed in reports expected to be published later.

Sulfur in Lignite

Samples of air-dried lignite from seven North Dakota mines were ignited to determine the percentage of sulfur volatized and retained in the ash. The sulfur retained by the ash varied from 10 to 92 percent of that present in the lignite, the percentage of retained sulfur decreasing with increase in ignition temperature. In general, the amount of retention in the residue did not correlate with distribution of sulfur forms in the lignite; however, lignites unusually high in pyrite sulfur lost more total sulfur upon ignition. In a study of sulfur in volatile-matter residues from analyses of lignites from four North Dakota mines, most of the sulfur retained was organic. Sulfate and sulfide sulfur were present in trace amounts. The average sulfur retention by volatile matter residues was 59 percent.

COAL MINING

Study of Known Recoverable Reserves of Coking Coal

The investigation of known recoverable reserves of coking coal was continued during the reporting period in Pennsylvania, West Virginia, Maryland, Kentucky, and Tennessee.

Sixteen county reports have been published in the series. Seven county reports were published during the reporting period, 2 each in Pennsylvania, Kentucky, and West Virginia and 1 in Maryland. The investigations are continuing in those States. Figure 2 shows the status of work in Pennsylvania, West Virginia, Kentucky, and Maryland, and figure 3 gives the same data for Tennessee.

Knott County, Ky.

The three important beds in this county from the standpoint of both production and remaining reserves are the Upper Elkhorn No. 3, Fire Clay, and Flag. Less

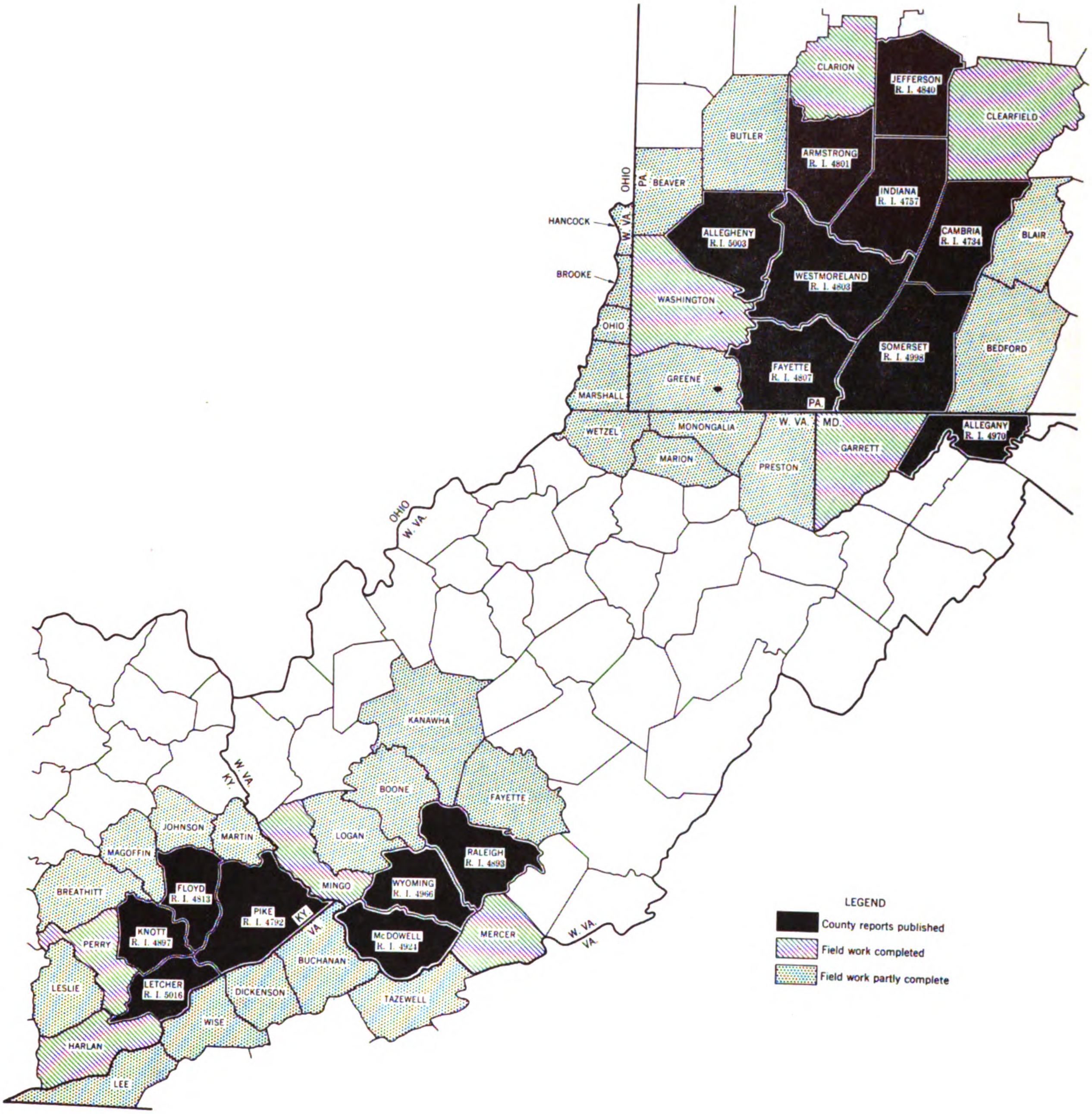

Figure 2. - Status of coking-coal-reserves investigations in Pennsylvania, West Virginia, Kentucky, and Maryland as of December 31, 1953.

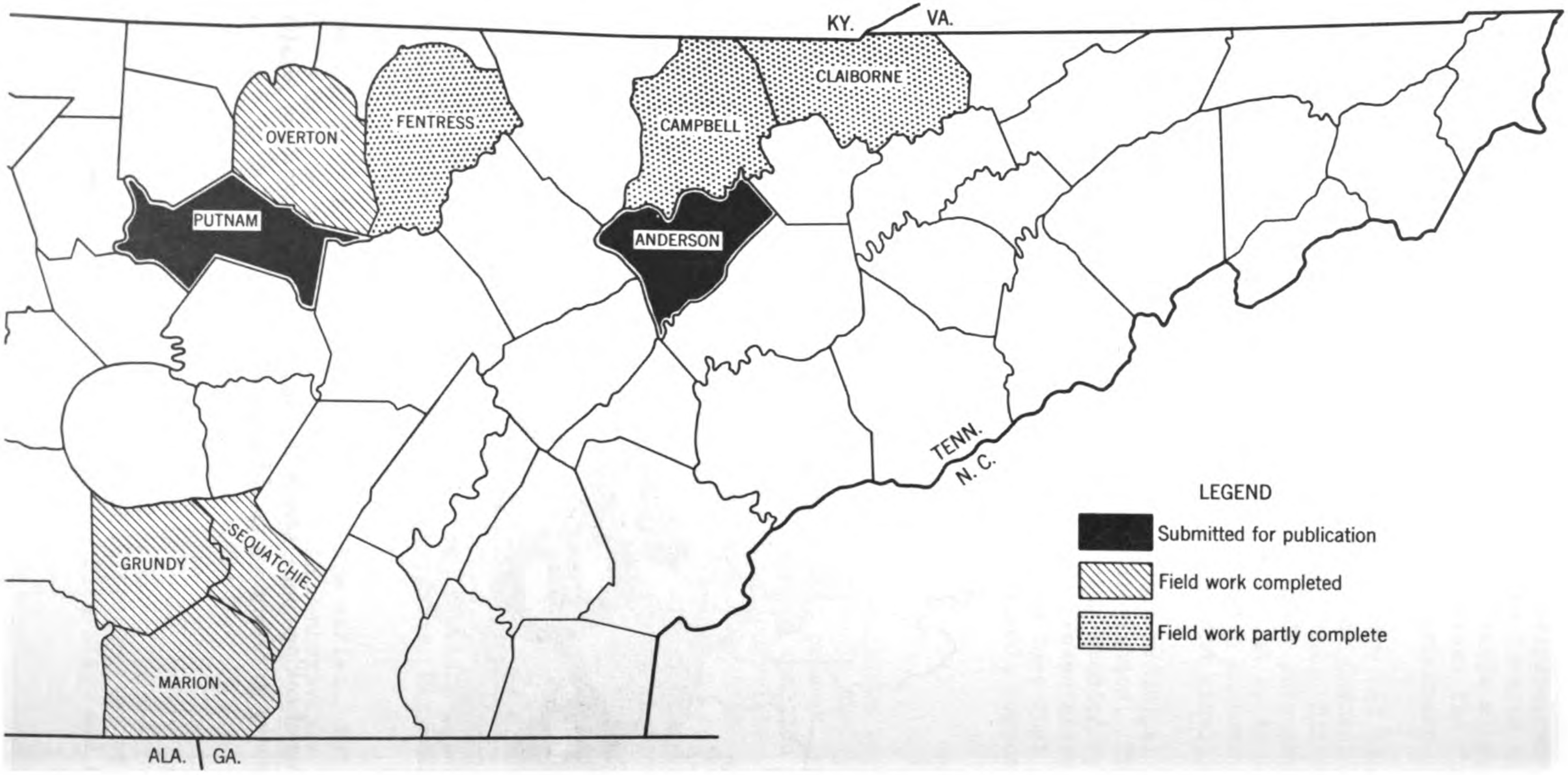

Figure 3. - Status of coking-coal-reserves investigation in Tennessee as of December 31, 1953.

important are the Upper Elkhorn No. 1, Upper Elkhorn No. 2, and Hindman beds. The Upper Elkhorn No. 3 bed contains the largest remaining known reserve.[21]

Tabulated estimates of known measured and indicated reserves are given for each of eight coal beds. As of January 1950 the remaining reserves in all beds are estimated at 1,859 million tons. Reserves in beds 28 inches and more thick are estimated to be 1,174 million tons.

Based on the weighted average recovery of 53.13 percent for all beds mined in this county, it is estimated that the recoverable reserves are 624 million tops. Maps of the Hindman, Flag, Fire Clay, Whitesburg, Amburgy, Upper Elkhorn No. 3, Upper Elkhorn No. 2, and Upper Elkhorn No. 1 coal beds are given in the report.

Coals in this county are high-volatile A bituminous. They contain low proportions of ash and sulfur generally and yield excellent metallurgical coke when blended and carbonized with coal of higher rank.

McDowell County, W. Va.

The six important beds in this county, in the order of importance from the standpoint of 1950 rate of production, are: Pocahontas No. 3, Pocahontas No. 4, Pocahontas No. 5, Sewell, Beckley, and Pocahontas No. 6. Less important beds are the Iaeger, Douglas, Welch, Pocahontas No. 9, and Eagle. The Pocahontas No. 3 bed has the largest remaining known reserves.[22]

Tabulated estimates of known and measured reserves are given for 18 coal beds. Other beds have been reported to occur in the county, but enough data were not available, and these beds have not been included in the estimates. As of January 1951 the remaining reserves in all beds are estimated to be 2,217 million tons. Reserves in beds 28 inches and more thick are estimated to be 1,731 million tons.

Based on the weighted average recovery of 62.1 percent for all beds mined in this county, it is estimated that the recoverable reserves are 1,075 million tons. Maps of the Eagle, Douglas, Iaeger, Sewell, Welch, Beckley, Fire Creek, Pocahontas No. 9, Pocahontas No. 6, Pocahontas No. 5, Pocahontas No. 4, and Pocahontas No. 3 beds are given in the report.

McDowell County coals are medium- and low-volatile bituminous and are valuable coking coals. The Pocahontas No. 3 has been the most important low-volatile coal; but, owing to expanding properties of medium- and low-volatile coals, blends with high-volatile coals usually are made for carbonizing in coke ovens.

Wyoming County, W. Va.

The five important beds, from the standpoint of present production, are the Pocahontas No. 3, No. 2 Gas, Sewell, Beckley, and Eagle. Beds of lesser importance are: Pocahontas No. 6, Cedar Grove, Winifrede, Douglas, and Chilton. The Pocahontas No. 3 bed contains the largest remaining known reserve.[23]

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[21] Dowd, J. J., Toenges, A. L., Abernethy, R. F., and Reynolds, D. A., Estimate of Known Recoverable Reserves of Coking Coal in Knott County, Ky. Bureau of Mines Rept. of Investigations 4897, 1952, 20 pp.

[22] Wallace, J. J., Dowd, J. J., Tavenner, W. H., Provost, J. M., Abernethy, R. F., and Reynolds, D. A., Estimate of Known Recoverable Reserves of Coking Coal in McDowell County, W. Va.: Bureau of Mines Rept. of Investigations 4924, 1952, 26 pp.

Reserves have been tabulated for 36 coal beds that are known to occur in this county. As in the adjoining McDowell County, other beds are reported to occur, but, based on available data, information was not adequate for estimating reserves. As of January 1951 the remaining reserves in all beds are estimated to be 2,665 million tons. Reserves in beds 28 inches and more thick are estimated to be 2,121 million tons.

Based on the weighted average recovery of 55.0 percent for all beds mined in this county, it is estimated that recoverable reserves are 1,167 million tons. Maps of the Winifrede, Chilton, Williamson, Cedar Grove, Alma, No. 2 Gas, Eagle, Gilbert, Douglas, Sewell, Beckley, Fire Creek, Pocahontas No. 6, Pocahontas No. 4, and Pocahontas No. 3 beds are given in the report.

Because most of the Wyoming County coals are medium- and low-volatile bituminous and expand during carbonization, they are blended with high-volatile contracting coals when used to make metallurgical coke in slot-type ovens.

Allegany County, Md.

The four important beds, from the standpoint of known recoverable reserves, are the Lower Bakerstown, Upper Freeport, Upper Bakerstown, and Upper Kittanning. Beds of less importance, on the same basis, are Sewickley, Waynesburg, Pittsburgh, and Barton. The Lower Bakerstown bed contains the largest remaining known reserve.[24]

Estimates of known measured and indicated reserves have been tabulated for nine coal beds in the county, and only the Harlem has no reserves considered recoverable. As of January 1951, the remaining reserves in all beds are estimated to be 556 million tons. Reserves in beds 28 inches and more thick are estimated to be 304 million tons.

Based on the weighted average recovery of 49.8 percent for all beds mined in this county, it is estimated that recoverable reserves are 152 million tons. Maps of the Waynesburg, Sewickley, Pittsburgh, Barton, Harlem, Upper Bakerstown, Lower Bakerstown, Upper Freeport, and Upper Kittanning beds are given.

Allegany County coals are low-volatile bituminous, strongly coking, and expand upon carbonization, hence they are usually blended with high-volatile coals for use in slot-type coke ovens.

Somerset County, Pa.

The four important beds in the county from the standpoint of known recoverable reserves are the Upper Kittanning, Lower Kittanning, Upper Freeport, and Lower

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[23] Wallace, J. J., Dowd, J. J., Tavenner, W. H., Provost, J. M., Abernethy, R. F., and Reynolds, D. A., Estimate of Known Recoverable Reserves of Coking Coal in Wyoming County, W. Va.: Bureau of Mines Rept. of Investigations 4966, 1953, 39 pp.

[24] Wallace, J. J., Dowd, J. J., Williams, L., Abernethy, R. F., and Reynolds, D. A., Estimate of Known Recoverable Reserves in Allegany County, Md.: Bureau of Mines Rept. of Investigations 4970, 1953, 18 pp.

Freeport. Beds of less importance on the same basis are: Middle Kittanning, Clarion, Pittsburgh, and Redstone. The Upper Kittanning bed contains the largest remaining known reserves.[25]

Tabulated estimates of known measured and indicated reserves are given for each of eight coal beds. As of January 1952 the remaining reserves in all beds are estimated at 1,859 million tons. Reserves in beds 28 inches and more thick are estimated to be 1,351 million tons.

Based on the weighted average recovery of 57.2 percent for all beds mined in this county, it is estimated that the recoverable reserves are 773 million tons. Maps of the Redstone, Pittsburgh, Upper Freeport, Lower Freeport, Upper Kittanning, and Lower Kittanning beds are given in the report.

Somerset County coals are low- and medium-volatile bituminous and generally are blended with high-volatile coals for carbonization in modern coke ovens because of their expanding properties.

Allegheny County, Pa.

From the standpoint of present production and recoverable reserves, there are two beds of major importance - Pittsburgh and the Upper Freeport - and one of less importance - the Redstone. The Upper Freeport bed has the largest remaining known reserves.[26]

Reserves have been tabulated for five coal beds. As of January 1953 the remaining reserves in all beds are estimated to be 832 million tons. Reserves in beds 28 inches and more thick are estimated at 768 million tons.

Based on the weighted average recovery of 53.3 percent for all beds mined in this county, it is estimated that the recoverable reserves are 384 million tons. Maps of the Redstone, Pittsburgh, Upper Freeport, Middle Kittanning, and Lower Kittanning beds are given in the report.

Allegheny County coals are high-volatile A bituminous and are strongly coking. Owing to contracting properties of the coal during carbonization, blends with low- or medium-volatile coal improve the physical properties of the resulting coke.

Letcher County, Ky.

The two important coal beds in this county from the standpoint of present production are the Upper Elkhorn No. 3 and the Fire Clay. Beds of lesser importance are the Whitesburg, Flag, Haddix, Elkhorn, Leader and Amburgy. The Upper Elkhorn No. 3 bed contains the largest remaining known reserve.[27]

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[25] Wallace, J. J., Dowd, J. J., Bowsher, J. A., Abernethy, R. F., and Reynolds, D. A., Estimate of Known Recoverable Reserves of Coking Coal in Somerset County, Pa.: Bureau of Mines Rept. of Investigations 4998, 1953, 20 pp.

[26] Wallace, J. J., Dowd, J. J., Provost, J. M., Abernethy, R. F., and Reynolds, D. A., Estimate of Known Recoverable Reserves of Coking Coal in Allegheny County, Pa.: Bureau of Mines Rept. of Investigations 5003, 1953, 16 pp.

[27] Wallace, J. J., Dowd, J. J., Travis, R. G., Abernethy, R. F., and Reynolds, D. A., Estimate of Known Recoverable Reserves of Coking Coal in Letcher County, Ky.: Bureau of Mines Rept. of Investigations 5016, 1953, 26 pp.

Reserves in 11 beds have been tabulated to show measured and indicated reserves. As of January 1952, the remaining reserves in all beds are estimated to be 1,353 million tons. Reserves in beds 28 inches or more thick are 1,056 million tons.

Based on the weighted average recovery of 54.1 percent for all beds mined in this county, it is estimated that the recoverable reserves are 571 million tons. Maps of the Hindman, Flag, Haddix, Fire Clay, Whitesburg, Amburgy, Upper Elkhorn No. 3, Elkhorn Leader, Upper Elkhorn No. 2, Upper Elkhorn No. 1, and Lower Elkhorn beds are included in the report.

Coals of the major producing beds are high-volatile A bituminous and generally are low in moisture, ash, and sulfur. When blended with low- or medium-volatile coals and carbonized, excellent coke is produced.

Tennessee

The Bureau's investigation of known, recoverable reserves of coking coal was begun in Tennessee in September 1952. A report covering the reserves in the Wilder bed, or, as it is locally known, the Bon Air No. 2 bed, in Putnam County, was being reproduced at the time of reporting. The report on Anderson County was completed, estimates were completed in 4 other counties, and field work was in progress in 3 other counties.

Coal Investigations: Alaska and United States

Alaska

The development and processing of coal to supply the fuel requirements of military installations and for essential civilian needs continues to be the immediate objective of the Bureau's coal investigations in Alaska. Long-range objectives, essential to the orderly economic growth of the Territory, include: Investigation and development of the indicated large coal reserves; development of mining methods for more economic recovery; beneficiation; and investigations to develop the full utilization of the heat, power, and byproduct potentials of this major resource. The development program is being carried out in close cooperation with the Federal Geological Survey.

Core drilling in the Matanuska field was continued in an attempt to extend the known reserves and to encourage additional production by independent operators. This field is the main source of coal supply for the Anchorage defense zone; principal production is from one mine operating in the Wishbone Hill area. Drilling in this area was continued to increase the known reserves and to indicate the feasibility and method of deep level development of the Wishbone Hill syncline.

Early in 1953 investigations were made in the Moose Creek area of the Matanuska field. At the Buffalo mine, 3 drillholes established continuity of the formerly worked Premier (Buffalo) series of coal beds for an additional 1,700 feet down dip from the lower levels of the old mine workings. Moose Creek holes 2 and 3 established the existence of the overlying Jonesville series of coal beds and greatly increased the indicated reserves. This work supplements a previous investigation made in 1943. Rehabilitation of the Buffalo mine was suspended in April 1953 pending a decision on an application for additional Government financing.

The privately financed Pioneer Coal & Coke Co. began developing a 3-1/2-foot bed of coal that crops out near the old Pioneer mine; the company also is developing a 6-foot bed of clean coal on the Baxter property.

Bureau investigations adjacent to the strip mine at Houston on the Alaska Railroad were suspended in the fall of 1952. Three core-drill holes proved that the so-called strip bed persisted in rank, thickness, and dip for at least 4,000 feet down dip from the open-pit workings. The drilling also determined the presence of a similar bed approximately 260 feet vertically below the strip bed, but neither bed is considered suitable for underground mining. A considerable flow of brackish water and some gas were encountered in all three holes. A report is being prepared on the work at Houston.

Tennessee

The Bureau of Mines cooperated technically with the Division of Geology of the State of Tennessee to investigate Tennessee coal reserves. This was done by diamond drilling, geologic study, and engineering examinations. The Division of Geology at Tennessee entered into a diamond-drilling contract to obtain coal cores for petrographic study and analysis and rock cores for geologic study. Results of the drilling are being published by the Division of Geology in 3 charts, 2 of which have been published.[28] A third chart will be published for the northern field at a later date.

Active drilling began December 19, 1951, and was completed May 25, 1953. Seventy-three holes were drilled, with a total footage of 24,623 feet. In all, 45 cores of coals over 18 inches thick were shipped to the Bureau of Mines at Pittsburgh, Pa., for petrographic study and analysis. A split of one-half of each core was returned to the Tennessee Division of Geology Core Library. Twenty-three different coal beds were penetrated in the drilling. These beds, in a descending stratigraphic order, are: Peewee, Walnut Mountain, Red Ash, Sharp, Beech Grove, Big Mary, Windrock, Upper Pioneer, Lower Pioneer, Jordan, Joyner, Jellico, Blue Gem, Black Wax, Coal Creek, Ant, Poplar Creek, Hooper, Rex, Morgan Springs, Lantana, Upper Sewanee, and Richland. The drilling was exploratory and the results will be used with other data for estimating recoverable coking-coal reserves.

North Carolina

A Bureau bulletin[29] gives results of an investigation by diamond drilling of coal deposits in the Deep River Coal field, Chatham Lee, and Moore Counties, N. Car., undertaken at the request of North Carolina officials, to determine the thickness and continuity of the coal beds, physical conditions in and surrounding the beds that would affect future mining, and petrographic and chemical characteristics of the coals. Known reserves in this field were estimated to be 87,548,000 tons of high-volatile A bituminous coal, of which 50 percent is considered recoverable by present mining methods.

Foreign Coal Investigations and Technical Assistance

The Bureau of Mines is cooperating with the Foreign Operations Administration by participating in the United States Government Point 4 program of technical assistance to improve economic conditions in the underdeveloped areas of the world by encouraging wider and more efficient use of natural resources. Because coal as a source of heat and energy and as a metallurgical reagent is essential to industrial progress, utilization of coal resources received major attention in the early stages of development programs under Point 4. From July 1, 1952, to December 31, 1953, Bureau coal technologists gave technical assistance to Brazil, Colombia, Republic of the Philippines, Afghanistan, Pakistan, and India. New projects have been proposed for Peru, Brazil, and Thailand, the latter being limited to laboratory test work.

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[28] Jewell, J. W., and Luther, E. T., Results of Exploratory Drilling, Monterey Coal Field, Tennessee, 1953, 1 chart; Results of Exploratory Drilling, Southern Coal Field, 1953, 1 chart: Division of Geology of Tennessee.

[29] See footnote 20.

Brazil

In response to a request from the Brazilian D.N.P.M. (mines bureau), a Federal Bureau of Mines coal-preparation specialist assisted in designing and operating the Cia. Siderurgica Nacional coal washery at Tubarao. Recent plant tests indicate that through improved operating techniques a metallurgical coal suitable for blending with imported southern Appalachian coking coal can be produced from Brazilian deposits, thus increasing the proportion of local coal that can be used to produce coke for steelmaking. Lack of good coking coal in Brazil has been a major deterrent to large-scale development of the vast iron resources of the country, among the largest and highest grade deposits in the world. This development thus can be a significant factor in the industrial development of the country.

Colombia

The Bureau of Mines is cooperating technically in a program for future development of coal production in the Cauca Valley of Colombia, where present coal production is centered. At the request of Colombian officials, the Bureau is advising on the design and initial operation of a washery being built at Cali. A Bureau of Mines mining technologist has been assigned to Colombia for the next 2 years, and the services of a coal-preparation engineer have been provided intermittently to assist in planning the washing plant. This is a continuing project to help expand Colombian coal production, supply fuel needs for new industries, and export coal to obtain needed foreign exchange.

Philippine Islands

Coal deposits, which occur on Cebu, Mindanao, and Bataan Islands, are being utilized only on a very small scale, and the Philippines desire to use more local resources, in lieu of imported petroleum, to reduce foreign-exchange requirements. Two Bureau solid-fuels experts visited the Philippines for 2 months to explore resources and make utilization studies. Bureau laboratories are now studying coal samples from the Philippines to determine analysis and use characteristics. It is proposed to assign 2 engineers to aid the Philippine Bureau of Mines for 2 years in carrying out the program in the islands.

Afghanistan

Although coal production in Afghanistan is extremely small by United States standards, it is highly important to the Afghanis. Coal is the major fuel for space heating during the cold winters in the nation's capital, Kabul, and for the country's small industry. At the request of the Afghanistan Government and FOA, two Bureau of Mines engineers are now assigned to cooperate in training native technicians in increasing production and to carry out programs initiated by Bureau personnel previously assigned to this area. Through very elementary mechanization, use of better mining methods, and improved health, safety, and living conditions for the workers, production has nearly doubled to about 14,000 tons annually, thus eliminating fuel shortages in Kabul during the cold months and making more fuel available for industrial needs.

India

The development of an economic source of fuel is prerequisite to creating industry in underdeveloped southern India. One such potential source is the lignite deposit near Neyveli, Madras, with an estimated minable reserve of 400 million tons. Although this deposit has been known for some time, its exploitation has been retarded because of unsolved technological problems, including the fact that the lignite is underlain by permeable artesian water-bearing formations. Because the underlying water is under high pressure, exploitation involves, in addition to water disposal, the problem of overcoming the constant tendency for the bottom of the pit to heave. The topography of the area does not permit natural drainage, and there is a high ratio of overburden to coal, averaging 7:1. Despite this, open-pit mining is indicated as the most economical method of operation. At the suggestion of a Bureau mining engineer, an experimental pit was begun to determine basic engineering data, and it is anticipated that enough test-pit data for development of a mining plan will have been obtained within a year. Meanwhile, Bureau stations in this country are studying the characteristics of this Madras lignite and possible methods of utilizing it.

To supplement the hydroelectric power from the Damodar Valley, northeast of Calcutta, especially during the dry season, a 200,000-kilowatt, coal-fired steam plant has been constructed at Bokaro, using coal from the high-ash Bermo bed, which is not suitable for locomotive use. A Bureau of Mines engineer is assisting the Damodar Valley Corp., the eventual operator, in studying: (1) The best layout of the open-pit mine, considering economic removal and transportation of coal and overburden; (2) selection of the most suitable type and size of equipment, such as shovels draglines, etc.; (3) economic advisability of installing coal-washing equipment.

Pakistan

An important project in Pakistan under the technical assistance program is construction of a plant to manufacture ammonium sulfate, using indigenous gypsum and coal as raw materials. The gypsum is of good quality and abounds in West Pakistan, but utilization of the Pakistan coal, which is of inferior grade, noncoking, and high in sulfur, required much preliminary study to determine whether it could be used to generate gas in equipment of standard design. Proposals submitted for constructing the plant envisaged two different processes for coal gasification; these have been examined by Bureau engineers, one of whom is serving as consultant to FOA. Recommendations were made to guide final decisions. The analysis and caking characteristics of the coal were determined in Bureau laboratories in the United States. During 1953, bids for procurement of various components of the plant were invited and contracts concluded.

Natural-Gas Storage in Coal-Mining Areas

A report was made on problems encountered when storing natural gas underground in coal-mining areas.[30] In addition to giving reasons for storing natural gas underground in coal-mining areas and the hazards involved therein, the report points out the necessity of close cooperation between the coal and natural-gas industries when gas is stored near active coal mines.

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[30] Wheeler, H. P., Jr., and Eckard, W. E., Underground Storage of Natural Gas in Coal-Mining Areas: Bureau of Mines Inf. Circ. 7654, 1952, 11 pp.

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Mining Methods and Practices

Trends in Anthracite Mining

As the overall output of anthracite has declined, the percentages of coal loaded mechanically underground and recovered from strip pits have increased greatly.[31] Of the total underground production in 1952, 41 percent was loaded mechanically, as compared with 33 percent in 1942. Preliminary estimates for 1953, indicate that the percentage of underground production loaded mechanically increased still further as anthracite production declined sharply to an estimated 30,000,000 net tons. The coal beds of the Northern field are relatively flat when compared with the more steeply pitching beds of the other fields and are therefore more adaptable to machine loading. This is believed to account for the fact that 86 percent of the total loaded mechanically in 1952 was produced in the Northern field, as compared with 14 percent for the other 3 fields combined.

Owing to the necessity of obtaining coal at the lowest possible cost, the percentage of anthracite recovered from strip pits has increased greatly also. In 1952, 30 percent of the total fresh-mined output came from strip pits, compared with 17 percent in 1942. Of the total strip tonnage in 1952, 56 percent was obtained in the Schuylkill region, 24 percent in the Wyoming region, and 20 percent in the Lehigh region. The relatively high rate of production in the Schuylkill region is due to the outcropping of many thick, highly pitching beds.

Anthracite Mechanical Mining Research

A caving method for steeply pitching anthracite beds,[32] shown in figure 4, was applied successfully to a 14-foot bed pitching 70°. Over 50,000 tons was mined using this new method, with an average output of underground employees of 38.8 tons per man per shift in the section mined, after the miners had become familiar with the method. This may be compared to a 26.3-ton figure for the conventional slant-chute method, which the caving method replaced, and to the 2.75-ton figure reported for the anthracite region as a whole in 1950, the last year cited. The method introduced is safer than conventional methods, because long chutes are eliminated, the amount of explosive is reduced, and transportation of timber and supplies up long travelways is no longer required. Working areas are concentrated, permitting closer supervision of the workmen. Data from the test show that 89.5 percent of the coal was recovered without excessive dilution and that more than 90 percent actually was recovered.

The Bureau of Mines and an anthracite-producing company are cooperating in underground experiments on timbering methods and strata control, in which there has been little change in the past 75 years, and relatively meager data are available. The first phase has been to investigate pneumatic rock packing, which was first carried out in Germany in 1924 and has since been used at mines in Great Britain. In Britain this method of backfilling has shown its superiority over the common method of allowing the mine roof to cave and hand-packing rock to control the overlying strata. Experiments in operating an imported German pneumatic packing

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[31] Bureau of Mines, Pennsylvania Anthracite, 1952: Mineral Market Report, M.M.S. 2208, September 1953, 23 pp.

[32] Allan, Andrew, Jr., and Davies, R. S., Anthracite Mechanical-Mining Investigations, Progress Report 5: Recovery of Anthracite in a Steeply Pitching Bed by Induced Caving: Bureau of Mines Rept. of Investigations 5013, 1953, 12 pp.

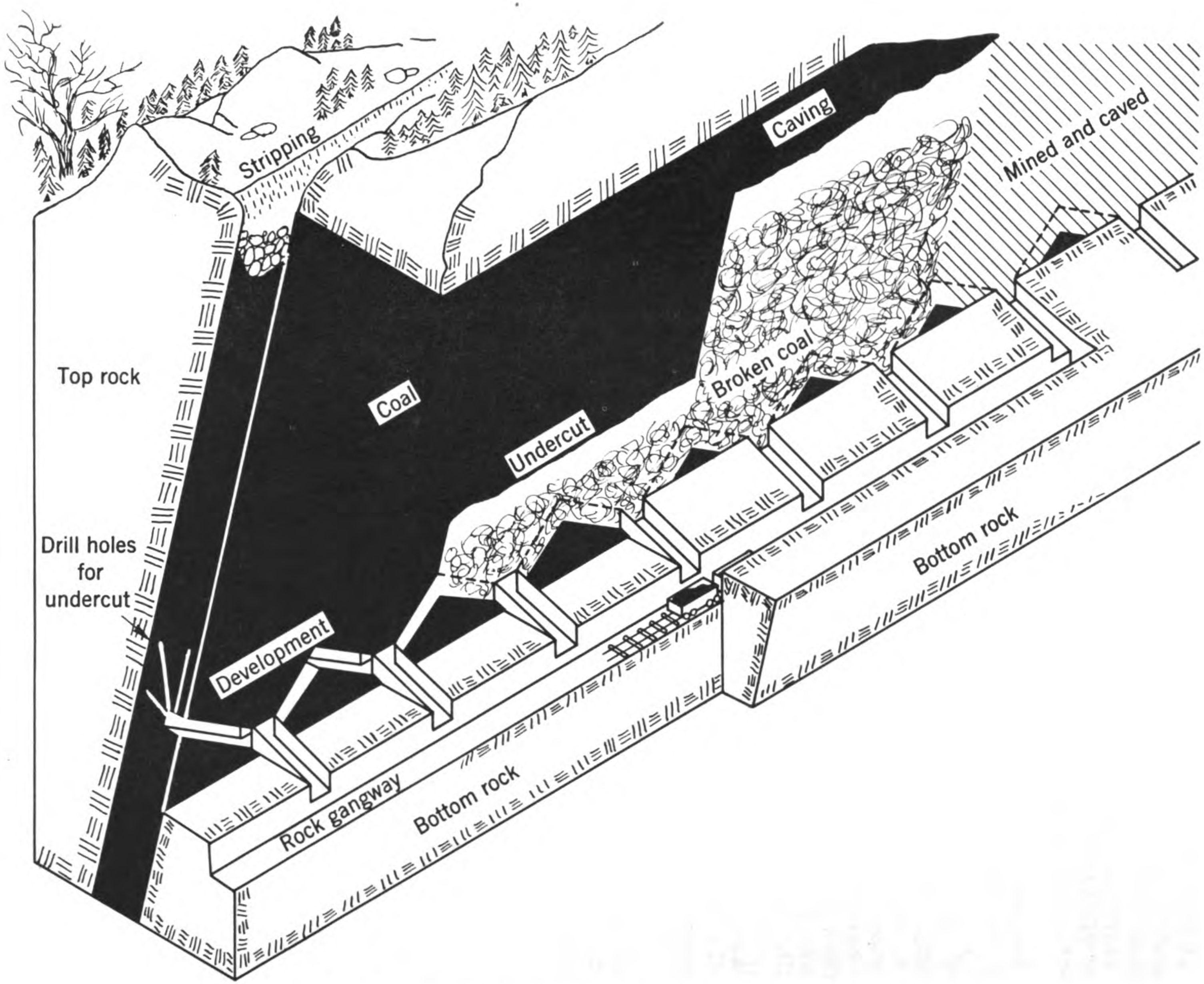

Figure 4. - Induced caving applied to steeply pitching anthracite beds.

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machine,[33] furnished by the Bureau, were carried on for 2 years in an anthracite mine at Plymouth, Pa., were 22,834 tons of rock - 3 inches and smaller - from the preparation plant (breaker) was blown by compressed air through 6-inch pipe into 15 chambers at the average rate of 40.6 tons per hour. The plan of the mine showing area backfilled is shown in figure 5. No coal pillars were mined in this area after it was packed with rock, as the purpose was to test the performance of the packing machine, although it is proposed for use to permit pillar recovery.

The performance of the packing machine in the preliminary tests was promising enough to prompt the cooperating company to try it in another area at the same colliery where first mining has been completed and the remaining coal pillars are to be mined. Here the mine roof is weak, making recovery of the pillars both difficult and dangerous with the conventional mining method, where only wooden timbers are used to support the roof. This backfilling should make it possible to recover coal that otherwise would have to be left in place to support surface improvements and water-bearing sand and gravel that overlie the coal in this area. Backfilling is important because the future anthracite production from a large portion of the Northern anthracite field will depend, to a large extent, on backfilling to avoid breaking and caving of the overlying strata.

A Bureau study of use of machines for underground development in pitching anthracite beds, previously reported, revealed that the time required to erect timber to support the roof and sides of openings required almost half of the faceworking time. The possibilities of using a movable, telescopic type of steel shield at the face instead of the conventional wooden timber were suggested by Bureau engineers engaged in this work. A sketch of the proposed shield is shown in figure 6. Such a shield, successfully developed, would provide miners working at the face with maximum protection from falls of roof and ribs, the cause of most fatal accidents in coal mines. Permanent timbers could then be placed behind the shield, independently of the facework, as the face advanced. To design such a shield, it was necessary to secure information on the loads it must support by actually measuring the loads borne by underground roadway supports.[34] A testing-machine manufacturer cooperated by making a load-measuring and recording instrument for testing by the Bureau. The device consisted of 12 mechanical-electrical dynanometer cells and an automatic recorder. The cells were installed on the collars of 3 adjacent underground timber sets supporting the roof in a 6- by 7-foot coal gangway driven in a 50-foot coal bed inclined at 80°. Loads were recorded electrically on a recorder mounted conveniently nearby. The location of cells and recorder in the mine are shown in figure 7. These records showed that the maximum rates of load increase occurred during the first 10- or 12-foot advance of the coal face, regardless of time. They also gave the maximum total load on each of the three sets under various stages of face advance. Certain defects found within the instrument while in use have been corrected, and it has been made permissible to meet the requirements of the Bureau.

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[33] Landsidle, Clayton A., Hartley, John C., and Buch, John W., Anthracite Mechanical Mining Investigations. Progress Report 6. Preliminary Testing of Brieden Pneumatic Packing Machine: Bureau of Mines Rept. of Investigations 4978, 1953, 13 pp.

[34] Allan, Andrew, Jr., Kaar, P. H., and Cooner, J. D., Sr., Anthracite Mechanical Mining Investigations. Progress Report 9. Measurements of Loads Borne by Underground-Roadway Supports: Bureau of Mines Rept. of Investigations 4946, 1953, 12 pp.

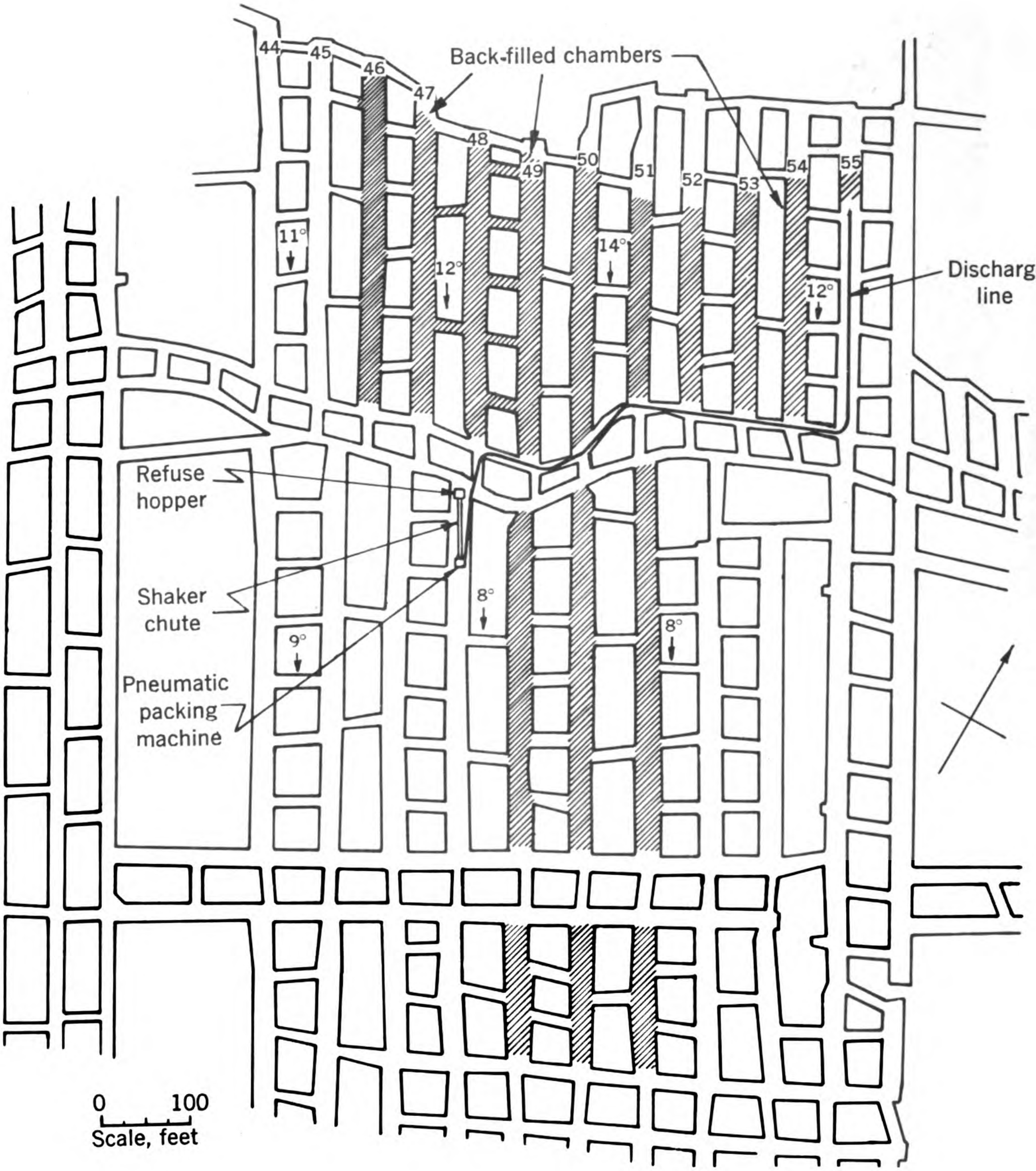

Figure 5. - Initial installation of the Brieden pneumatic packing machine.

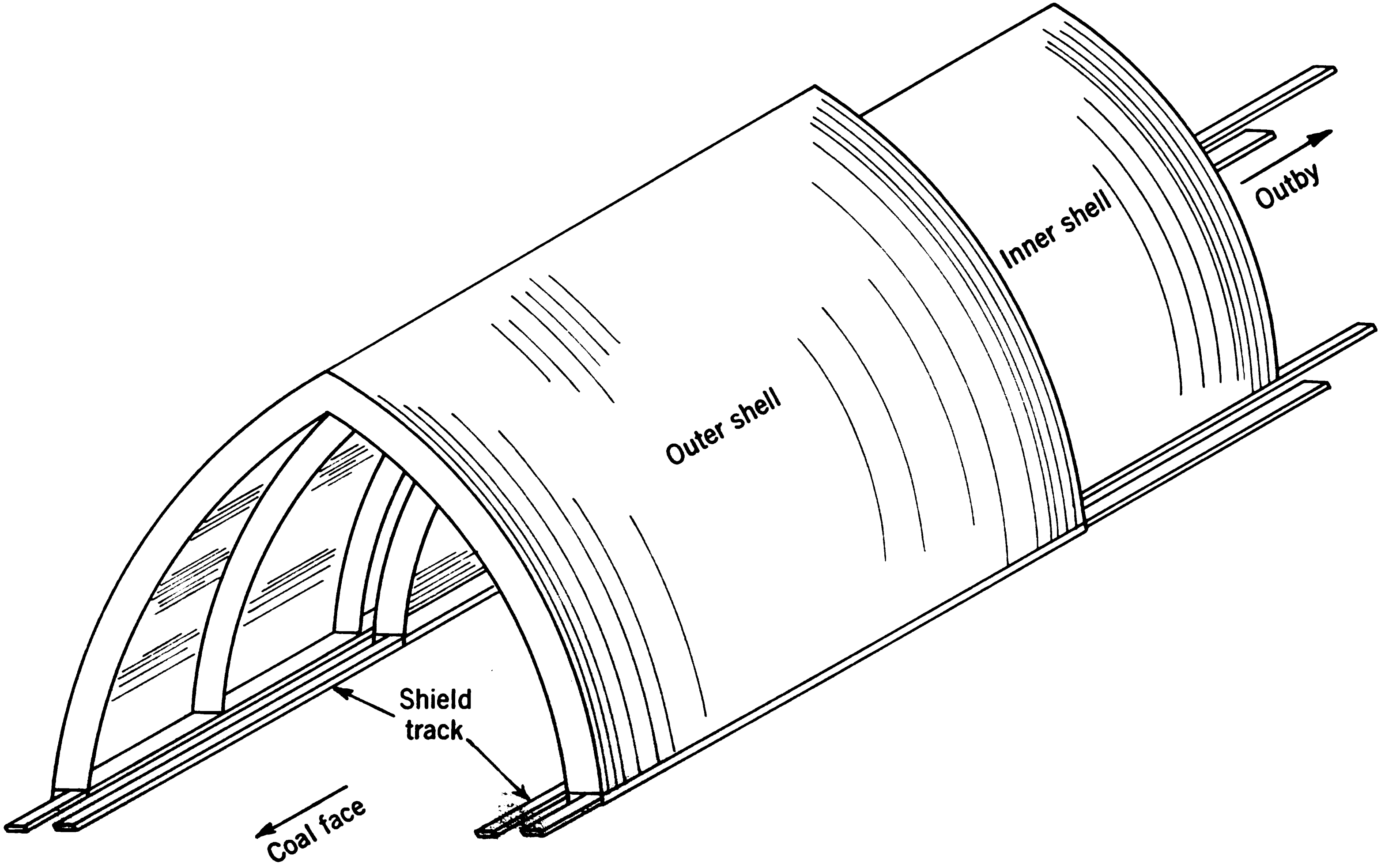

Figure 6. - Proposed telescopic steel shield.

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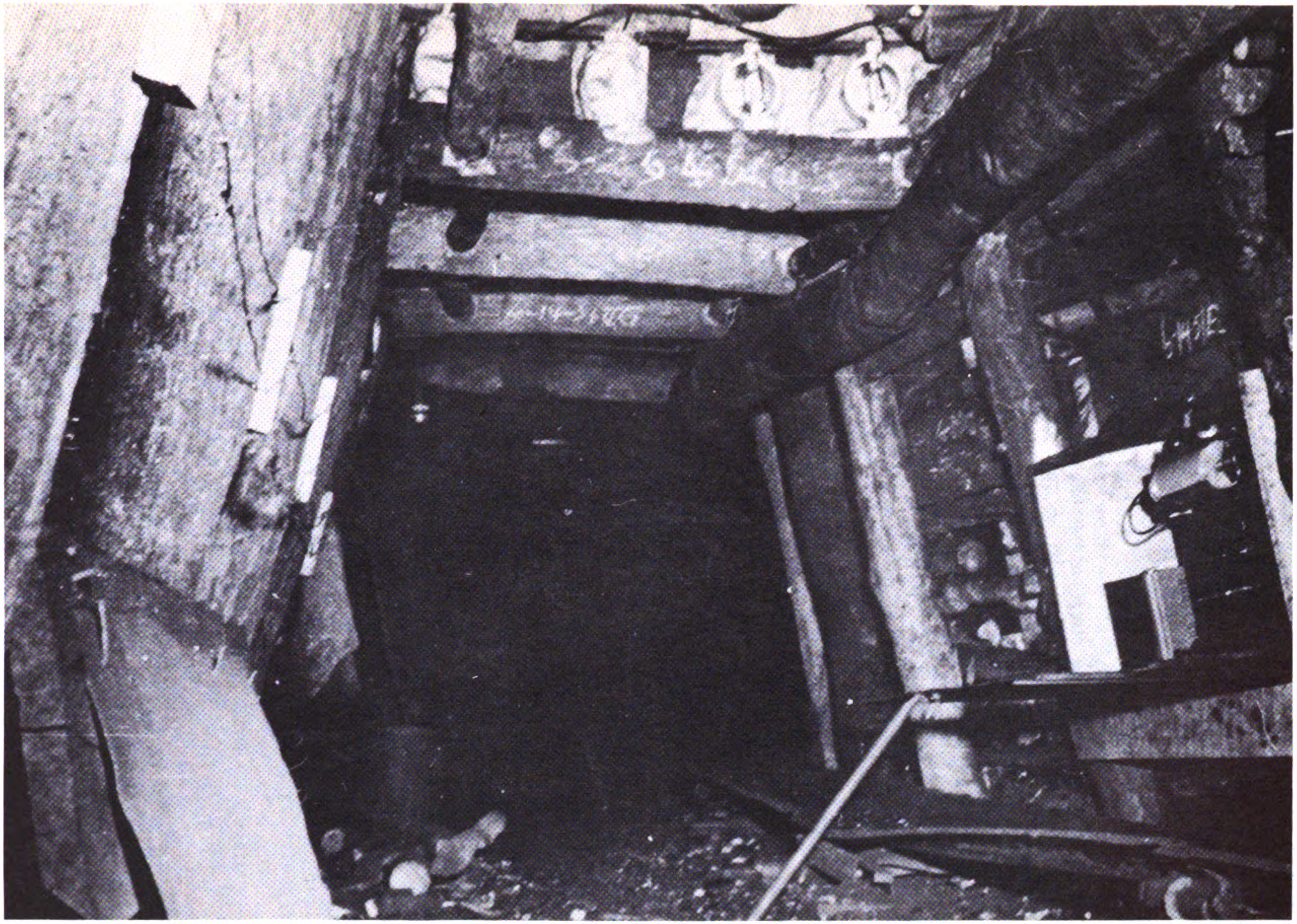

Figure 7. - Underground installation of load cells and recording device.

A mining method to reduce face costs[35] was conducted in cooperation with an anthracite-producing company in the Southern field, in a section where the coal bed is 9 to 10 feet thick and on an 82° pitch. After development (driving the gangway and airway) had been completed (see fig. 8), the experimental section was 270 feet long, with the height of the unmined coal up the pitch varying from 35 to 60 feet. With this relatively short vertical distance, it was considered that these conditions offered an excellent opportunity to experiment with a longhole method of mining. Accordingly, the recovery of the coal was begun by first drilling a 2-inch hole 30 feet in the solid coal at the inby end of the gangway. Six similar holes then were drilled in a circle surrounding the first hole. Firing these holes made a circular opening 3 feet in diameter and 26 feet high, which gave a free face for another hole that was drilled 30 feet vertically into the solid coal and 8 feet outby the initial opening. Coal broken by a blast in this hole occupied a space 35 feet high, 20 feet along the gangway, and the full width of the bed. Only one hole was necessary for each subsequent fall blasted. This experimental work recovered 3,500 tons of coal at an average production of 11.4 tons per man per shift, and only 0.115 pound of permissible explosive was required per ton of coal recovered. In addition, solid coal that remained over face timbers gave the miners added protection.

Mechanization at Bituminous-Coal and Lignite Mines

For many years the Bureau of Mines has made an annual survey of the extent and growth of the use of the principal types of machinery at bituminous-coal and lignite mines.[36] The statistical series covering coal cut by machine, cut by hand, and shot from the solid, begun in 1896, was continued, as were the series on strip mining, begun in 1914, that on mechanical loading, begun in 1923, that on methods of haulage, begun in 1924, and that on power drills for shot holes, begun in 1940. In addition, data on the latest developments in mechanization (namely, augers and continuous mining machines) were published for the first time for 1952. The increased use of machinery in coal mines has been nothing short of phenomenal. In 1952, approximately 84 percent of all soft coal was loaded mechanically or strip-mined, and preliminary data indicate the trend to increased mechanization continued into 1953.

Bituminous Coal-Mining Studies

Use of continuous-mining machines in room-and-pillar mining was studied in 20 mines in 6 States in beds of different thickness and under varied mining conditions. A report in preparation will present mining plans and other pertinent data for each operation and can be used by operators of small mines with limited or no research funds to compare their own operating conditions with those of the mines studied. The smaller mine operator can use these data to determine a feasible plan for using higher capacity equipment.

The study of longwall mining with an imported German coal planer in the Pocahontas No. 4 bed at the Stotesbury No. 11 mine of the Eastern Gas & Fuel

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[35] Allan, Andrew Jr., and Davies, R. S., Anthracite Mechanical-Mining Investigations. Progress Report 7. Longhole Retreat Mining of a Steeply Pitching Anthracite Bed: Bureau of Mines Rept. of Investigations 4925, 1952, 10 pp.

[36] Young, W. H., Anderson, R. L., and Hall, E. M., Bituminous Coal and Lignite in 1952: Bureau of Mines Mineral Market Summary 2222, October 1953, 96 pp.

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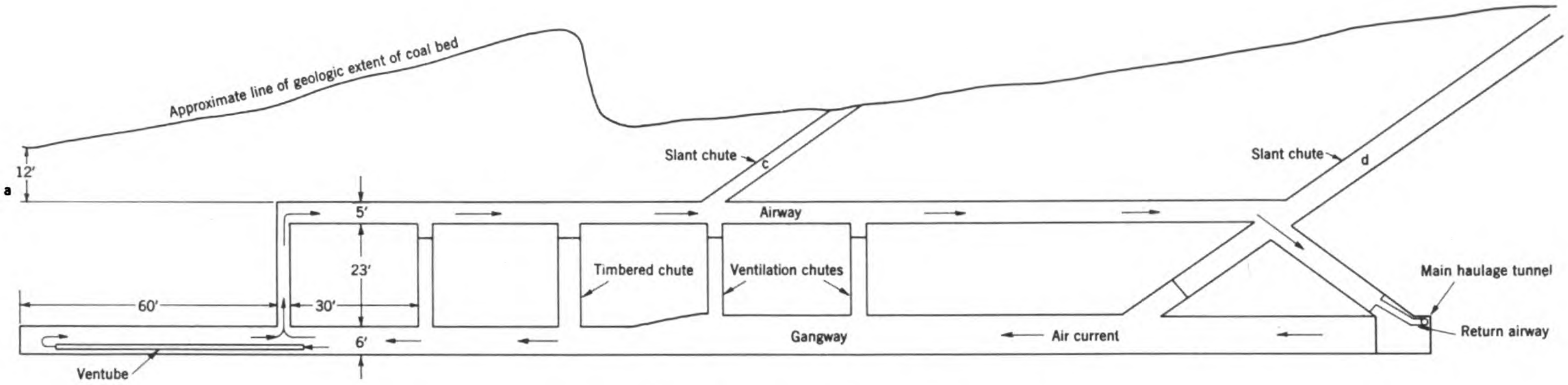
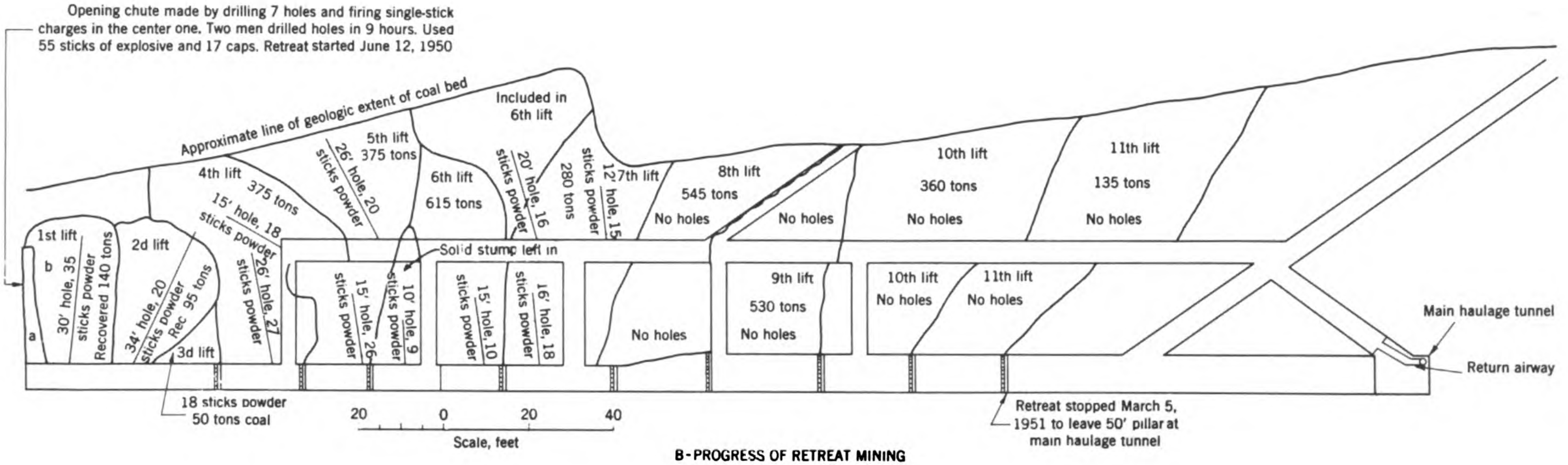


A-DEVELOPMENT WORK AT START OF RETREAT


Opening chute made by drilling 7 holes and firing single-stick charges in the center one. Two men drilled holes in 9 hours. Used 55 sticks of explosive and 17 caps. Retreat started June 12, 1950
Approximate line of geologic extent of coal bed
Included in 6th lift
1st lift
b
a
30′ hole, 35 sticks powder
Recovered 140 tons
2d lift
34′ hole, 20 sticks powder
Rec 95 tons
3d lift
18 sticks powder
50 tons coal
4th lift
375 tons
15′ hole, 18 sticks powder
26′ hole, 27 sticks powder
5th lift
375 tons
26′ hole, 20 sticks powder
6th lift
615 tons
15′ hole, 26 sticks powder
10′ hole, 9 sticks powder
Solid stump left in
15′ hole, 10 sticks powder
16′ hole, 18 sticks powder
20′ hole, 16 sticks powder
280 tons
12′ hole, 15 sticks powder
7th lift
8th lift
545 tons
No holes
No holes
No holes
9th lift
530 tons
No holes
10th lift
360 tons
No holes
10th lift
No holes
11th lift
135 tons
No holes
11th lift
No holes
Main haulage tunnel
Return airway
Retreat stopped March 5, 1951 to leave 50′ pillar at main haulage tunnel
20
0
20
40
Scale, feet

B-PROGRESS OF RETREAT MINING

Figure 8. - Progress of longhole retreat mining.

Associates, Helen, W. Va.,[37/38/39] was continued in cooperation with the mining company and the American representative of the manufacturer of the planer. The first such experiment in the United States was completed when a block of coal, 1,441 feet long and 328 feet wide was completely mined without leaving any pillars of coal to support the roof.

In conventional room-and-pillar mining in the United States, when pillars are not recovered, the average recovery of coal is just a little over 50 percent of the original coal in place. In addition, it is difficult to coordinate the various operations accurately; as a result, it is necessary to have more working places in a mine than necessary to produce a given tonnage, to insure having a place available at all times for the loading operation. Even if delays are eliminated, time is lost by moving unit crews of the cycle from one working place to the next.

The planer, operated on a longwall face, is a continuous mining machine. It is pulled back and forth from one end of the face to the other with no delay, all the while mining and automatically loading the coal onto a face conveyor as the planer moves. This eliminates cutting, drilling, and blasting the coal in the conventional mining cycle where continuous miners are not used. The roof at the working face, when the coal planer is used, is supported by steel props and I-beam caps, which are recovered and reused. (See fig. 9.) As mining progresses, the steel supports farthest from the face are pulled systematically, allowing the roof to cave. Elimination of explosives for blasting and of wood props for supporting the roof not only saved the cost of such materials but also the cost of their surface and underground handling. Another saving was realized by eliminating the need for rock dusting, since the face was never as much as half the maximum safe distance from the caved area allowable for mining without dusting. A layout of the panel is shown in figure 10.

A 78-percent recovery had been attained with conventional mining methods at this mine, which is much higher than the average. However, using the longwall method with the planer, the recovery of coal was increased to 83 percent. Also, productivity per man per shift was over 20 percent more than in the conventional mining system at this mine. The planer used in this study has mined three adjacent longwall panels and has been moved to another mine of the same company, where it is still operating. Two other American companies have imported planer units, and the three planers are being used in coal beds of different thickness and with widely different mining conditions.

Roof-Fall Fatalities in Coal Mines

Federal investigation of 235 fatalities from falls of roof, face, and rib that were charged to the bituminous-coal industry during 1952[40] showed that 62 percent of all the fatalities that occurred underground in bituminous-coal and lignite mines

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[37] Haley, W. A., Dowd, J. J., and Turnbull, L. A., Modified Longwall Mining with a German Coal Planer (Plow) in the Pocahontas No. 4 Coal Bed, Helen, W. Va.: Bureau of Mines Rept. of Investigations 4922, 1952, 13 pp.

[38] Haley, W. A , Modified Longwall Mining with the Loebbe Coal Planer (Plow): Proc. Coal Min. Inst. America, 66th Ann. Rept., 1952, pp. 23-37.

[39] Haley, W. A., Experiment With a German Coal Planer on a Longwall Face: Coal Mine Mod., 1952, pp. 117-122.

[40] Kingery, D. S., Falls of Roof, the No. 1 Killer at Bituminous Coal Mines, 1952: Bureau of Mines HSS 415, Mineral Industry Surveys, 1953, 13 pp.

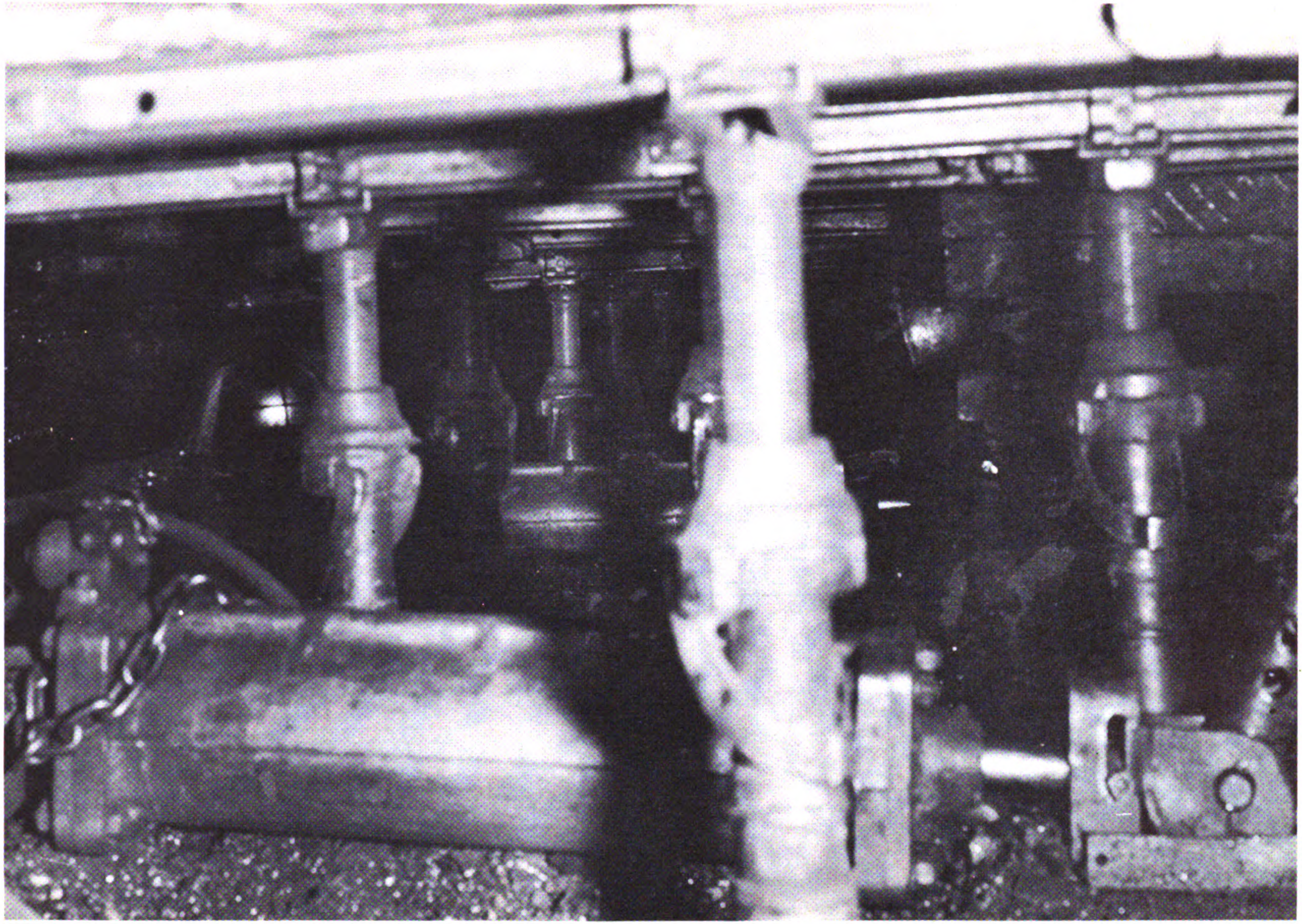

Figure 9. - Steel props and I-beam caps supporting roof at face.

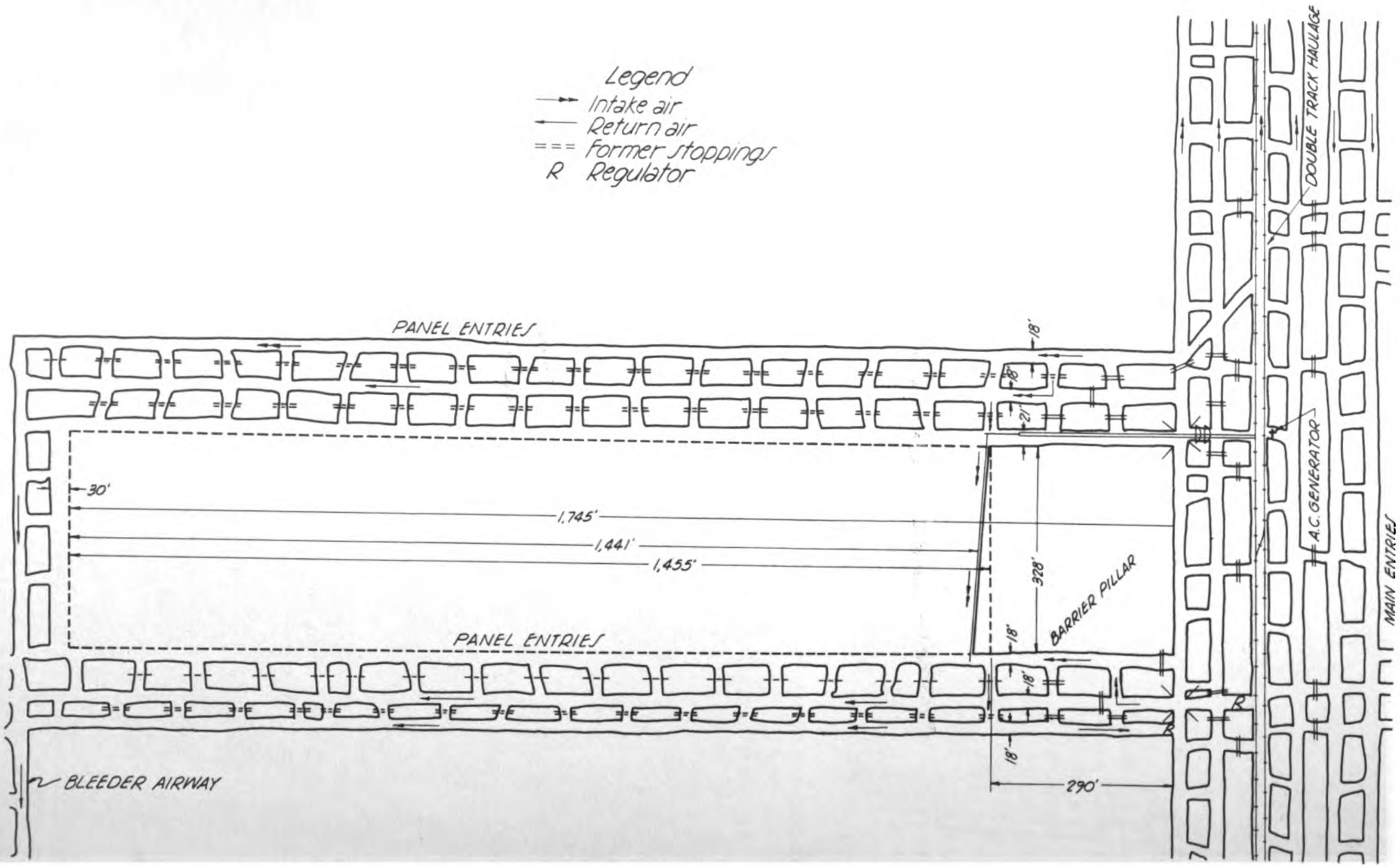

Figure 10. - Plan of completed experimental panel.

resulted from this cause. Human failure was responsible for 87 percent of the fatalities. Analysis of reports on 93 fatalities underground at the anthracite mines of Pennsylvania in 1952[41] reveals that 40 percent of these were caused by falls of roof, face, or rib; 24 percent was chargeable to haulage; and the remaining 36 percent were due to rush of material, gas explosions, explosives, machinery, falls of persons, and miscellaneous.

Recommendations for preventing and reducing the incidence of roof-fall accidents included: (1) Regardless of roof conditions, minimum standards for systematic roof support suited to the conditions and the mining system of each mine should be adopted and followed; (2) supervisors should be given safety training; (3) roof, ribs, and face of places where men work or travel should be inspected as often as necessary and dangerous conditions promptly corrected; (4) crosscuts, rooms, and entries should not be opened opposite each other; (5) permanent timbers should not be removed by hand; (6) roof bolting should be adopted where practical; (7) loose roof should be taken down; (8) danger signs should be put up where men have been withdrawn on account of bad roof; (9) employees should cooperate fully in observing a timbering plan; (10) dangerous conditions should be corrected promptly, or men should withdraw and notify their supervisor; and (11) employees should attend training classes.

Haulage Fatalities in Coal Mines

Investigation and study of 111 haulage fatalities in 1952[42] covered occurrences in 11 producing States. The victims were killed in many different ways. The most frequent were: Caught by moving equipment, injured by runaway equipment, collisions, contacted low roof or crossbars, or squeezed between haulage equipment and a timber leg, coal rib, or the face. The accident rate by age range for haulage crews in this study did not follow the usual pattern, since no one age group appeared enough higher than another to establish a definite pattern. The ratio of injuries to job experience shows that the inexperienced workers, especially shuttle-car operators, are quite likely to become injured. This study shows further that haulage employees considered to be experienced are very often injured and indicates the need for occasional review of work practices, safety meetings, and improved supervision.

This study shows that, although the chain of circumstances varied, the physical hazards, unsafe practices, and other contributing factors were quite similar, proving that haulage accidents follow a recurring pattern. The Bureau recommended that employees be selected on the basis of physical ability, mental qualifications, and stability; that job training and certification be established; that safety rules be promulgated to govern the actions of haulage employees; that the haulage system be planned on the basis of present and future requirements; that a maintenance program should remove defective equipment before breakdowns occur; and that supervision should assure corrective measures and necessary job instructions.

Analysis of Coal-Mine Accident Data

A complete statistical report on deaths and injuries to persons in the coal-mining industries for 1949, with summary tabulations for 1943-47, shows that falls of roof and face caused more than half the fatalities and about a quarter of the deaths and injuries.[43] Injury rates in hand-loading mines were almost the same as in the mines where coal was loaded mechanically. Average severity of all injuries was 152.6 days lost per injury, in 1949, and the fatality rate was 0.91 deaths per million man hours.

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[41] Mather, J. V., Fatalities at Pennsylvania Anthracite Mines, 1952: Bureau of Mines HSS 417, Mineral Industry Surveys, 1953, 17 pp.

[42] Kingery, D. S., Haulage Fatalities in Bituminous Mines, 1952: Bureau of Mines HSS 416, Mineral Industry Surveys, 1953, 18 pp.

Roof Control

Considerable progress was made in introducing bolting as a means of roof support in coal mines. As of January 1, 1952, over 650 of the larger mechanized mines had adopted the method, and of these 85 use bolts exclusively. Approximately 2.1 million bolts a month are used in coal mining.

The Bureau of Mines, in cooperation with several mining companies and State agencies, is carrying on a program of research and investigation not only on problems involving roof bolting but also on the broader subject of roof control in general. An improved centrifugal-testing apparatus has been designed and built in the Bureau of Mines laboratory at College Park, Md., which is unique in that it incorporates the use of resistance gages to measure directly the strains in a rotating model without testing it to failure.[44] Owing to this feature, a more rapid testing method can be used; furthermore, model materials need not be restricted to those of the prototype. The behavior of any structure in which strains of significant magnitude are produced by its own weight may be studied in small scale in the apparatus, subjected to simulated gravity loading. The model is rotated in a centrifuge to induce centrifugal forces in it and these, like the gravitational forces in the full-size structure, act on the volume elements and are proportional to the masses thereof. Centrifugal testing is, therefore, applicable to the design of underground mine openings and to the study of similar ground-control problems. It constitutes an experimental method for determining the state of strain in a structure for which other analytical methods are excessively laborious or even impossible.

Tests on slotted-type roof bolts, as normally supplied to mine operators and installed in a conventional manner, indicate that a torque of 260 foot-pounds applied to a nut on a slotted-type roof bolt will produce a load of 10,000 ± 2,700 pounds on the bolt.[45] Also, the results show that neither the type of thread nor the type of rock materially affects the torque-load relationship for slotted-type bolts. In spite of the errors introduced by frictional effects in the nut-bolt-bearing plate assembly, the torque wrench is considered to be a practical instrument for checking the tightness of roof bolts.

A study,[46] to find the advantages and savings that were made by roof bolting a main entry, as compared to supporting the same roof with peg timbering, revealed that the estimated cost of peg timbering of 14,000 linear feet was $100,000, as compared with an actual cost of $37,000 for roof bolting. The installation was completely successful as not 100 pounds of rock had fallen from the 2-1/2 miles of entry in 18 months.

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[43] Reese, S. T., Wrenn, Virginia E., and Reid, Elizabeth J., Injury Experience in Coal Mining, 1949: Bureau of Mines Bull. 525, 1953, 131 pp.

[44] Panek, L. A., Centrifugal Testing Apparatus for Mine-Structure Stress Analysis: Bureau of Mines Rept. of Investigations 4883, 1952, 22 pp.

[45] Barry, A. J., Panek, L. A., and McCormick, J. A., Use of Torque Wrench to Determine Load in Roof Bolts. Part 1. Slotted-Type Bolts: Bureau of Mines Rept. of Investigations 4967, 1953, 7 pp.

[46] Kelly, L. W., Economics Through Roof Bolting in an Indiana Coal Mine: Bureau of Mines Inf. Circ. 7653, 1952, 10 pp.

Data obtained from on-the-site observations have been compiled to describe the equipment and installation methods used for satisfactory suspension roof support in a large-diameter tunnel.[47] Neither a lost-time injury nor a fatality attributable to roof falls occurred in the East Delaware Tunnel from May 8, 1951, to May 20, 1952. Approximately 124,350 roof bolts have been installed and have satisfactorily supported about 65,187 linear feet of roof, thereby effecting safer working conditions, a tremendous saving in vitally needed steel, and increased efficiency.

Mine-Timber Preservation by Collar Method

A study is being conducted in Washington to determine the feasibility of the collar method of impregnation as an inexpensive method of preserving mine timber.[48] Preservative chemicals were introduced into 28 growing trees. Timbers from these trees have been placed in a coal mine and their tendency to decay is being compared to that of adjacent untreated sets. Several years will be required before final conclusions can be drawn but results to date have been encouraging.

Anthracite Flood Prevention

To determine what short-range programs might be possible to prevent the inflow of water into the anthracite mines of Pennsylvania, studies were made of surface water seepage into the mines.[49][50][51] Similarly, studies were made of barrier pillars in each field.[52][53][54] The large amount of water seepage into mines from large rivers, and the physical condition of barrier pillars, give added emphasis to the need for a gravity-tunnel system as both a short-range and long-range solution of the anthracite mine-water problem. Plans for a drainage tunnel from Eddy Creek in the Lackawanna Basin of the Northern field to Conowingo, Md., are being formulated, and construction projects will be recommended to meet the most urgent problem in the Lackawanna Basin first.

Mine Air and Dust

In connection with the Bureau's program of coal-mine inspection, conducted under the provisions of the Federal Coal-Mine Safety Act, approximately 21,000 samples of mine air were analyzed to determine the adequacy of ventilation in coal mines, to detect and aid in eliminating hazards from flammable and toxic gases in mines, to provide information necessary in controlling and extinguishing fires in coal mines, and to supply information on various other matters pertaining to health and safety in coal mining. Approximately 1,800 examinations were conducted by microscopic, petrographic, X-ray diffraction, and spectrographic methods to determine the concentration and particle size of air-borne dusts, and the composition of such dusts and dust-source materials to evaluate their hygienic significance in the working environment of coal and other types of mines.

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[47] Platt, D. H., Roof Bolting the Delaware Aqueduct: Bureau of Mines Inf. Circ. 7652, 1952, 9 pp.

[48] Roberts, Edward, Mine Timber Preservation by the Collar Method: Progress Report 1: Bureau of Mines Rept. of Investigations 4980, 1953, 14 pp.

[49] Ash, S. H., Eaton, W. L., and Whaite, R. H., Surface-Water Seepage Into Anthracite Mines in the Lackawanna Basin, Northern Field, Anthracite Region of Pennsylvania: Bureau of Mines Bull. 518, 1952, 37 pp.

[50] Ash, S. H., and Link, H. B., Surface-Water Seepage Into Anthracite Mines in the Western Middle Field, Anthracite Region of Pennsylvania: Bureau of Mines Bull. 532, 1953, 26 pp.

[51] Ash, S. H., and Whaite, R. H., Surface-Water Seepage Into Anthracite Mines in the Wyoming Basin, Northern Field, Anthracite Region of Pennsylvania: Bureau of Mines Bull. 534, 1953, 30 pp.

[52] Ash, S. H., Davies, B. S., Jenkins, H. E., and Romischer, W. M., Barrier Pillars in the Lackawanna Basin, Northern Field, Anthracite Region of Pennsylvania: Bureau of Mines Bull. 517, 1952, 114 pp.

[53] Ash, S. H., Kennedy, D. O., Link, H. B., Romischer, W. M., Barrier Pillars in the Western Middle Field, Anthracite Region of Pennsylvania: Bureau of Mines Bull. 521, 1953, 92 pp.

[54] Ash, S. H., and Kynor, H. D., Barrier Pillars in the Southern Field, Anthracite Region of Pennsylvania: Bureau of Mines Bull. 526, 1953, 44 pp.

Coal-mine roof has been coated with water-resistant materials in some instances by the industry to prevent the spalling action of moisture condensed upon the roof strata from the ventilating current. As the use of the coating materials is not without some degree of hazard, information was developed relating to factors such as volatility, flammability, and toxicity of the materials that should be considered in formulating recommendations for their safe handling and application.55/

Because of the generally increasing realization that exposure of workers to air-borne dust in coal mines is potentially harmful, emphasis was placed on studies pertaining to dust control in coal mining.56/ Surveys were conducted in coal mines to determine concentrations of air-borne dusts produced by various mining operations, with particular attention to rock drilling and the free silica content of the strata drilled.57/ Other field studies of this nature, which are continuing, related to dust production and methods of dust control with continuous-mining equipment.

A survey of dust-control practices in the coal-mining industry was initiated and is in progress, through the medium of a questionnaire circulated to all Bureau of Mines coal-mine inspectors. The questionnaire is designed to provide information on the extent of application of dust-suppression measures in all coal-mining operations.

Approval testing of drill dust collectors was continued under the provisions of schedule of permissibility requirements issued in 1952, and 15 collectors were granted approval. These collectors are used chiefly to control dust produced in drilling coal mine roof to insert roof bolts.58/59/ The dust produced in this operation, because of its relatively high content of free silica, constitutes a greater potential health hazard than does the dust produced in drilling or cutting the coal face.

Approval testing was conducted on respiratory protective devices, including gas masks and dust respirators for personal protection in coal mines and other mineral industries. Five new approvals and 66 extensions of approvals were granted, representing modifications and improvements in design. The program of checking the

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55/ Berger, L. B., Roof-Coating Materials for Underground Mines and Precautions to Follow in Applying Them.: Proc. Coal Mining Inst. America, 1952, pp. 61-66.

56/ Westfield, J., Johnson, L., and Anderson, F. G., Coal Dust Sources and Control Underground: Coal Mine Mod. 1953, Am. Min. Cong., Washington, D. C., pp. 221-228.

57/ Owings, C. W., and Johnson, L., A Study to Determine Potential Dust Exposure in Connection With Intermittent Rock Drilling in Coal Mines: Bureau of Mines Rept. of Investigations 5004, 1953, 7 pp.

58/ Berger, L. B., Types of Dust Collectors Used in Conjunction With Roof-Bolt Drilling: Proc. Coal Min. Inst. America, 1952, pp. 116-120.

59/ Berger, L. B., Progress in Development of Dry Dust Collectors: Trans. 40th Nat. Safety Cong. and Exposition, Coal Min., vol. 7, 1952, pp. 33-36.

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performance of approved respiratory protective devices purchased in the open market was continued to ascertain whether performance of the commercially produced equipment is maintained at the same quality level as that of the device originally submitted for approval testing. Results of these tests were quite encouraging, as all the equipment met the requirements of the Bureau of Mines schedules under which they had been approved. In those instances where performance was significantly below that demonstrated in original approval tests, yet still within required limits, the manufacturers were notified that the quality of the device should be improved. To promote better understanding of the proper use of industrial respiratory protective equipment, a paper was prepared on the subject.[60]

Coal-Mine Ventilation

Ventilation surveys were conducted in several coal mines by the absolute pressure method that indicates the location of zones of above-average restriction to air flow in the overall ventilation pattern of the mine and therefore provides definite information for the improvement of ventilation efficiency. Development work on instrumentation for use in the mine-ventilation survey included an air-measuring instrument (Velometer) fitted with a length of flexible tubing to determine local pressure losses in mine airways, a water barometer for this use and for absolute pressure surveys, and a continuous methane recorder for underground use in connection with the study of methane emission from gob areas of certain coal mines as affected by changes in barometric pressure.

Design specifications were developed for a nonlinear electric analogue computer to facilitate the solution of complex air-distribution problems encountered in coal mine ventilation - problems so complex that ordinary mathematical solutions are too difficult and time-consuming to be of practical value. This computing device is being constructed.

Modern mechanical operations present many definite ventilating problems that, if not understood and corrected, may lead to explosion disasters. Rapid advance during the development in virgin coal increases problems of methane and coal-dust control. The common mining practice of working a series of small adjacent producing panels and driving rooms off both sides of room entries presents hazards of worked-out areas near active workings. Ventilation is complicated by these factors and is influenced by the movement of face and haulage equipment operating through ventilation aids, such as check curtains, doors, and line brattice. The continuous operation of electrical equipment within a concentrated face area, unless special preventive measures are taken, provides many ignition sources. The Bureau has presented plans and recommended practices to minimize the possibilities of methane accumulations in coal mines and reduce the chances of ignitions from electrical sources.[61][62]

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[60] Pearce, S. J., Use and Abuse of Respiratory Protective Devices: Trans. 40th Nat. Safety Cong. and Exposition, Ind. Safety, vol. 15, 1952, pp. 32-37.

[61] Ankeny, M. J., Westfield, James, Kingery, D. S., Ventilating Practices That Minimize Explosion Hazards in Bituminous-Coal Mines: Bureau of Mines Inf. Circ. 7648, 1952, 6 pp.

[62] Herbert, C. A., Some Factors Affecting and Suggested Ways for Improving Coal-Mine Ventilation, With Particular Reference to Mines in Illinois, Indiana, and Western Kentucky: Bureau of Mines Inf. Circ. 7656, 1953, 15 pp.

PREPARATION OF COAL

Trends in Mechanical Cleaning of Bituminous Coal

Since 1906 an annual survey of the mechanical cleaning of bituminous coal has been made.[63] Beginning with 1927 the tonnage mechanically cleaned was classified by type of equipment used. By 1952 almost half of the bituminous coal was mechanically cleaned. Beginning in 1940, statistics were given on the amount of coal crushed and treatment for allaying dust. In 1951, 22 percent of total production was crushed and 11 percent was treated for allaying dust.[64]

Coal Washing

Alaska

Technical assistance was given to the Evan Jones Coal Co. in the Matanuska field, Alaska, in restarting the company heavy-medium separation plant. The successful solution of operational problems at this long-idle plant resulted in substantially increased production.

In the interest of conservation and increased production, the thick but dirty "G" bed (now wasted) at the Usibelli Coal Mine, Inc., Healy Fork, Alaska, was sampled and subjected to washability examinations at the Bureau's Seattle, Wash., laboratory. The examination indicated that a large tonnage of coal can be upgraded to meet military specifications in heat value, but at an economic yield the ash content exceeds present limits.

Korea

At the request of the Economic Cooperation Administration, the preparation characteristics of South Korean anthracites were investigated.[65] Following cessation of hostilities between Japan and the Allied nations in 1945, much of the demand for electric power in South Korea was met by hydroelectric installations north of the 38th parallel. Power continued to flow into South Korea from the north until 1949 when the North Koreans severed the power lines into South Korea, forcing that section of the country to depend almost entirely upon coal to generate electric power.

The coal beds in South Korea are metamorphic, graphitic, and shaly and are found in lenses and pods rather than in distinct beds. Heavy faulting has introduced stringers of sandstone and shale into the coal beds, and in some places quartz veins cut through the coal matter. The coal is high-ash anthracite, and many of the coals degrade during mining, resulting in a high percentage of fine coal and dust in the mine-run size. Figure 11 shows the location of the coal fields in South Korea that are included in the report.

The Machari and Hambaek fields have special significance as they are the only adequate coal sources readily available to the 100,000-kw. pulverized-fuel plant at

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[63] Young, W. H., Anderson, R. L., and Hall, E. M., Bituminous Coal and Lignite in 1952: Bureau of Mines Mineral Market Summary 2222, October 1953, 96 pp.

[64] Young, W. H., and Anderson, R. L., Crushing and Treatment of Coal Continues Growth: Mechanization, vol. 17, No. 4, April 1953, pp. 190-191.

[65] Crentz, W. L., Preparation Characteristics of Anthracites in South Korea: Bureau of Mines Rept. of Investigations 5010, 1953, 17 pp.

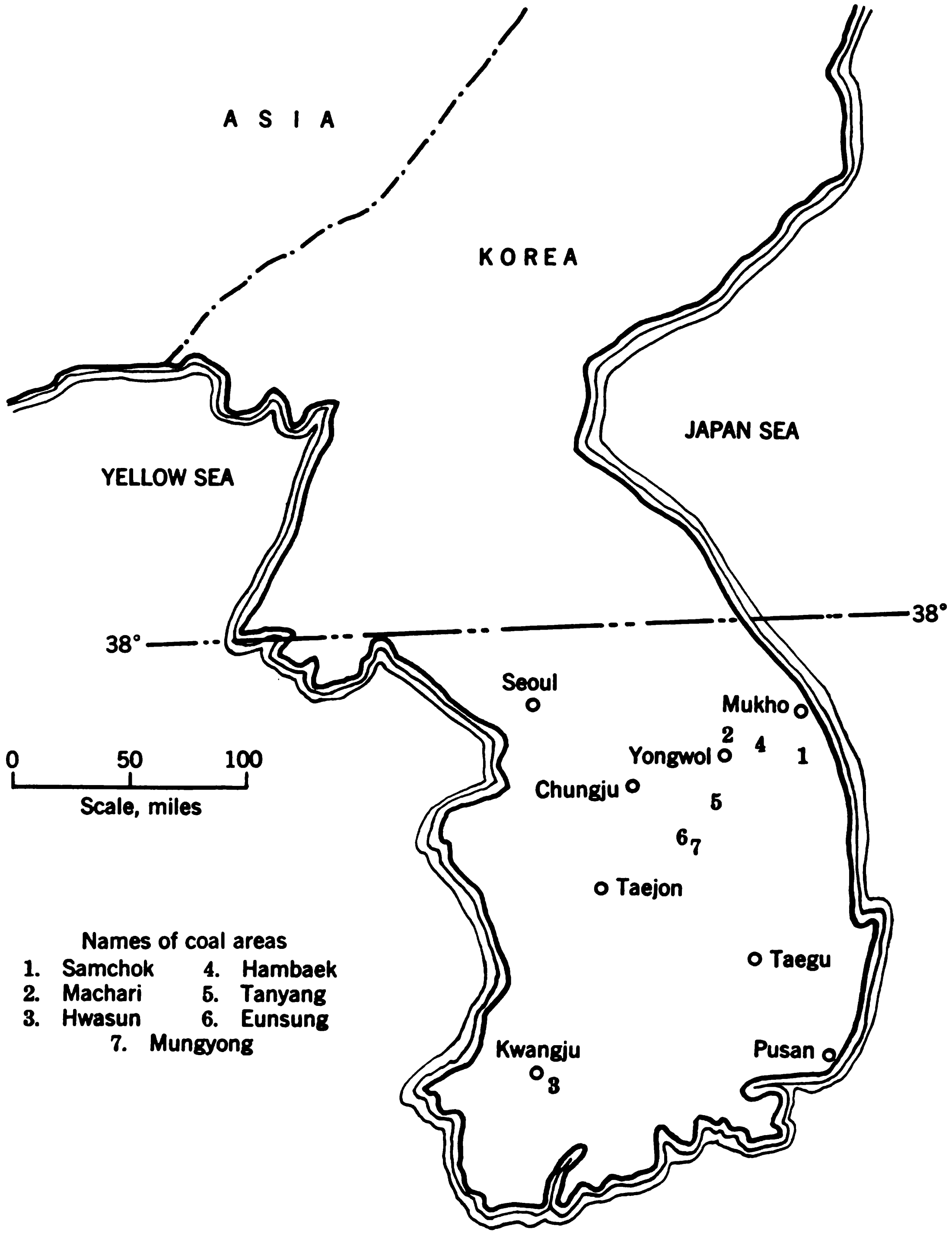

Figure 11. - Sketch map of South Korea, showing location of mining fields investigated.

Yongwol. Pneumatic cleaning of the Machari coal should prepare a clean coal containing about 30 percent ash. The Hambaek field is in the early stage of development. The quality of the coal appears to be somewhat superior to the Machari coal, and a clean coal containing about 20 percent ash could probably be obtained by mechanical cleaning.

The Samchok coal field is the most important coal body in South Korea. Careful cleaning would yield a washed product containing about 11 percent ash. The coal can be hauled by rail to the port city of Mukho for export, but rail facilities are not available to ship the coal west to the industries of South Korea. The Hwasun coal field is far south of the other coal-producing areas; and, although the quality of the raw product is comparable to that of the Samchok coal, the washed coal from the Hwasun field will contain 16 to 19 percent ash, depending upon the cleaning method. Coal from the Eunsung field can be mechanically cleaned to yield a low-ash washed product containing about 8 percent ash, but the field is isolated from the principal industrial centers and limited known reserves of coal may handicap development of this coal area. The Tanyang and Mungyong fields will probably never become important producers of coal. Adverse mining conditions and heavy concentration of impurities in the mined product have resulted in only sporadic operation in these areas.

Arkansas

A washability study was made of a sample of run-of-mine coal from the Quality Excelsior Coal Co. mine on the Upper Hartshorne bed near Hackett, Ark.66/ The Upper Hartshorne bed yields a low-volatile coal with excellent coking qualities. The run-of-mine coal used for this study included a certain amount of rock-contaminated machine cuttings, which are ordinarily gobbed and left in the mine. The washability curves derived from float-and-sink data in this study indicated that modern methods of coal cleaning would produce an excellent grade of coking coal from the Upper Hartshorne bed even if all machine cuttings were included as a part of the run-of-mine coal.

Cleaning and Dewatering Fine Coal

One of the most difficult problems in coal preparation is generally conceded to be the recovery, cleaning, and dewatering of fine coal with a top size of approximately 20-mesh. The Bureau-developed kerosine-flotation process, on the basis of experience to date in commercial plants, is believed to incorporate all the necessary elements for development to make it superior to anything else now available for the treatment of bituminous-coal fines in wet processes of coal preparation.67/ Additional study and investigation are still needed, however, to determine if certain phases of the process can be improved to such an extent as to make it more widely acceptable to industry by improvements to increase the capacity of the flotation cells and decrease the reagent consumption.

66/ Gandrud, B. W., and Riley, H. L., Washability Study of the Upper Hartshorne Bed at the Quality Mine, Hackett, Ark.: Bureau of Mines Rept. of Investigations 4964, 1953, 17 pp.

67/ Gandrud, B. W., and Schiffman, L. E., [The Kerosine-Flotation Process for Fine-Coal Cleaning and Dewatering]: IV Congress International Du Chauffage Industrial, 2 Rue Des Tanneries, Paris, Group II, No. 213, 1952, 8 pp.

A new German process, known as Convertol, for cleaning and dewatering bituminous coal-washery slurries was described.[68] The process was developed by the research staff of Deutsche Kohlenbergbau-Leitung, the association of coal producers in Western Germany. A small quantity of heavy oil is added to the slurry and dispersed over the surfaces of the coal particles by agitating the slurry and oil in a high-speed mill. After oiling, the slurry is treated in a centrifuge where the oil-treated coal particles bridge the centrifuge screen perforations and are retained in the machine, whereas the refuse and clay particles remain dispersed in the water and are rejected with the effluent. The Germans report that the centrifuge coal product contains virtually no free refuse material and only 8 to 10 percent of surface moisture.

The first phase of an investigation to determine factors in the design and operation of launder screens for cleaning fine sizes of anthracite has been completed, and reports covering the study are being published. The study was made to provide design and operating information that will assist coal operators in making maximum use of the launder screen to size, screen, classify, and deslime the smaller anthracite sizes (Buckwheat Nos. 1 through 5).

Dense-Medium Processes

The dense-medium process, in which magnetite suspensions are used for cleaning coal, is being adopted at a pace outstripping its own technology, with the result that lack of information on fundamental performance characteristics has hampered application of the process to some individual coal-cleaning problems. The heavy-medium pilot plant shown in figure 12 was built at the Bureau station at Seattle, Wash., in 1950 to develop needed data on this process. Over 50 runs have been made in the plant on 7 coals exhibiting a wide range in washability characteristics,[69] and the data obtained constitute a substantial contribution to the present knowledge of heavy-medium coal cleaning.

Separations were made in the plant with medium ranging from 1.30 to 1.69 specific gravity. With most of the coals treated in the usual range of washing densities, virtually perfect recovery of the clean coal was obtained; however, rejection of impurity was not as complete. Both the shape and the density of the impurity particles were found to affect the degree of completeness with which they were rejected. Size of particle also proved an important factor. Neither the recovery of coal nor the rejection of impurity was as good in the finer sizes of the feed as in the coarser.

Tests at low density demonstrated the application of the process to "skimming off" a superclean coal for special purposes. Data were obtained also on use of the process in treating unusually dirty coals not amenable to treatment by other methods. The results obtained on such coals affect the re-treatment of refuse by the dense-medium process. In none of these special applications is the efficiency as high as that obtained in ordinary operation. Some details of plant operation investigated suggest means for improving the performance of commercial units. For example, a gradation in density from the top to the bottom of the separating bath was found beneficial, and the need for some agitation of the bath was demonstrated.

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[68] Fraser, Thomas, Convertol Process of Coal-Slurry Treatment: Bureau of Mines Inf. Circ. 7660, 1953, 4 pp.

[69] Geer, M. R., Olds, W. A., and Yancey, H. F., Cleaning Various Coals in a Drum-Type Dense-Medium Pilot Plant: Min. Eng., July 1953, vol. 5, No. 7, pp. 696-705.

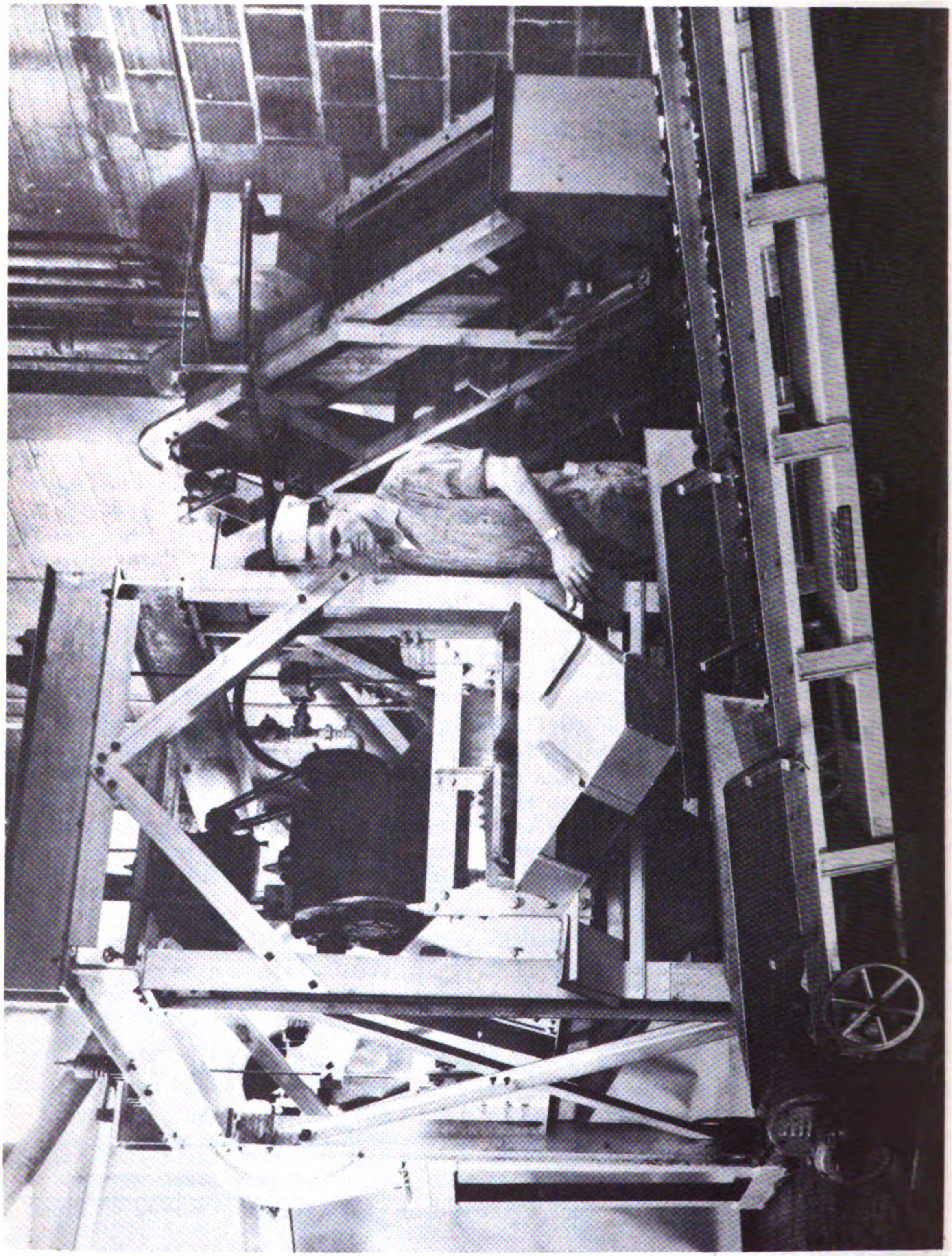

Figure 12. - Dense-medium pilot plant at Seattle Station, Bureau of Mines.

Another dense-medium pilot plant at the Bruceton, Pa., laboratories of the Bureau has been used for investigating the suitability of using coal-mine refuse as the dense medium in place of the magnetite used in commercial plants. Preliminary data indicate that close separation of coal and refuse is possible at quite low gravities, but additional tests and study are required before publication of results of the test program now in progress.

Preparation Characteristics of Coking Coal

The Nationwide investigation of preparation characteristics of coals that can be upgraded for use as metallurgical fuel, initiated in 1950 in the Appalachian region in Western Pennsylvania, has been extended to the coal fields of Eastern Kentucky. The preparation characteristics of the principal coal beds were reported on a county basis. During the reporting period, four reports were published. The most difficult washing problem is reduction of sulfur for metallurgical fuel.

Pike County, Ky.

Pike County contains large reserves of high-volatile bituminous coal, the principal reserves being in the Elkhorn group, which includes the Upper Elkhorn No. 3, Upper Elkhorn No. 2, Upper Elkhorn No. 1, and Lower Elkhorn beds.[70] The Winifrede, Williamson, and Bingham beds are of secondary importance, and the Coalburg, Fireclay, Whitesburg, Millard, Hagy, Auxier, and Elswick beds contribute little to the county's current coal production. The Coalburg and Winifrede beds contain moderate ash and low sulfur as mined, and simple washing methods will yield from these two beds a low-ash and low-sulfur clean coal that is chemically well suited for metallurgical use. The Fireclay bed is a thick bed containing alternating clean and dirty coal, but where 1 clean 40-inch bench is mined, float-and-sink tests show that a low-ash, low-sulfur float coal can be produced. The Whitesburg bed fluctuates in quality from low to high sulfur, and in the low-sulfur areas is suitable for metallurgical fuel, whereas in the high-sulfur areas the sulfur cannot be reduced readily, as shown by the investigation. The Williamson bed generally contains too much sulfur to permit its use as a coking coal, although there are low-sulfur areas where the coal is of metallurgical quality. The Upper Elkhorn No. 3, Upper Elkhorn No. 2, Upper Elkhorn No. 1, Lower Elkhorn, and Bingham beds, when washed, will yield a satisfactory metallurgical-grade coal over a wide geographical area. High sulfur occurs in the Upper Elkhorn No. 3 bed in the northern part of Pike County, where the bed is known locally as the Williamson-Thacker, and coal from this area cannot be washed to metallurgical grade. The Millard, Hagy, and Auxier beds are not mined extensively in the county, but the one sample collected from each of these beds indicated that a satisfactory metallurgical coal can be produced by preparation. The Elswick bed is only developed in the lowest valleys where it appears to contain high sulfur and is unsuited for use as metallurgical fuel. None of the beds containing high sulfur responded to liberation of sulfur by finer crushing.

Floyd County, Ky.

Floyd County contains large reserves of high-volatile bituminous coal, with principal reserves in the Upper Elkhorn No. 3, Upper Elkhorn No. 2, and Upper Elkhorn No. 1 beds.[71] The Hazard No. 7, Winifrede, Fireclay, Whitesburg, and Amburgy beds are of secondary importance. The Hazard No. 7 and Amburgy beds showed little possibility of becoming sources of metallurgical coal because of excessive sulfur in the clean or float coal. The Fireclay bed contains moderate ash and low sulfur in the central part of Floyd County, where the coal could be improved by washing to metallurgical grade. In the northern part of the county, the sulfur cannot be reduced enough by washing to meet present metallurgical requirements. The Whitesburg bed, when properly washed, will yield a moderate-ash, low-sulfur clean coal. The Upper Elkhorn No. 3 bed will yield a satisfactory metallurgical-grade washed coal over most of the county, and even the high-sulfur area in the north can be upgraded to metallurgical standards. Float-and-sink tests of Upper Elkhorn No. 2 bed coal samples showed that a low-ash and low-sulfur clean coal could be prepared by washing. The Upper Elkhorn No. 1 bed has been mined extensively in the southern half of Floyd County, and float-and-sink tests of coal from there indicate it to be amenable to washing to produce a low-ash and low-sulfur clean coal. One sample from the northern part of the county indicated that the coal could not be upgraded to metallurgical standards because of excessive sulfur. Fine crushing of the high-sulfur coals of Floyd County did not release a significant amount of sulfur.

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[70] Crentz, W. L., and Miller, J. W., Preparation Characteristics of Coal From Pike County, Ky.: Bureau of Mines Rept. of Investigations 4910, 1952, 28 pp.

[71] Crentz, W. L., and Miller, J. W., Preparation Characteristics of Coal From Floyd County, Ky.: Bureau of Mines Rept. of Investigations 4920, 1952, 21 pp.

Jefferson County, Pa.

The coals in Jefferson County are usually of high-volatile rank, although some medium-volatile coal is found in the eastern part of the county.[72] The principal coal beds, from a production standpoint, are the Lower Freeport and Lower Kittanning, whereas the Upper Freeport, Upper Kittanning, Middle Kittanning, Clarion, and Brookville are of secondary importance. The Upper Freeport bed is variable in thickness and quality, with low-sulfur areas where easy washing methods will produce high-quality metallurgical coal and high-sulfur areas where fine crushing and precise washing methods will yield a satisfactory metallurgical fuel and a middling product. The Lower Freeport bed is the most important coal deposit in Jefferson County, since over 50 percent of the county's output is from this bed. In the center of the county, the coal is chemically well suited for use as a metallurgical fuel, whereas a precise washing procedure is necessary to upgrade coal from this bed in the northeastern and southern portions of the county. The Upper Kittanning bed is not mined extensively, and only one sample was taken from this bed. The float-and-sink data show that a washed coal containing 1.50 percent sulfur probably could be obtained by fine crushing. The Middle Kittanning bed has only been mined on a small scale, and float-and-sink data from the one sample show that precise washing cannot reduce the sulfur and ash to make it suitable for metallurgical fuel. The Lower Kittanning bed, although seldom over 3 feet thick, is second in importance to the Lower Freeport because the coal can be upgraded to metallurgical grade by washing to reduce the ash. The Clarion bed is variable in quality, and there are areas from which the coal can be upgraded to metallurgical-grade. In other areas the sulfur is excessive and can only be reduced by precise washing and fine crushing. The Brookville bed is a satisfactory general-purpose fuel but cannot be washed to a metallurgical grade under present standards.

Knott County, Ky.

The coals of Knott County are high-volatile bituminous in rank. The principal reserves of coal are found in the Flag, Fire Clay, and Upper Elkhorn No. 3 beds.[73]

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[72] Crentz, W. L., and Miller, J. W., Preparation Characteristics of Coal From Jefferson County, Pa.: Bureau of Mines Rept. of Investigations 4941, 1953, 21 pp.

[73] Crentz, W. L., and Miller, J. W., Preparation Characteristics of Coal From Knott County, Ky.: Bureau of Mines Report of Investigations 4993, 1953, 30 pp.

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The Hindman bed has been mined extensively, and much of the output of coal from the county has come from this bed. The Upper Elkhorn No. 1 bed was mined extensively in the past, but mining from it diminished rapidly in recent years, and production is not important now. Small, sporadic, local production has come from the Francis, Haddix, Fire Clay Rider, Whitesburg, and Upper Elkhorn No. 2 beds. The Hindman and Upper Elkhorn No. 3 beds, because of excessive sulfur in the clean coal after float-and-sink testing, show little possibility of becoming sources of metallurgical coal, except in the northern part of the county where the Elkhorn No. 3 bed is low sulfur and meets metallurgical standards. One sample of the Francis bed was obtained, and the analysis showed low sulfur. The Flag bed was found to be readily washed to metallurgical grade in the southern part of the county, but very difficult to wash to metallurgical grade in the northern part of the county. The Haddix, Fire Clay Rider, Fire Clay, Whitesburg, Upper Elkhorn No. 2, and Upper Elkhorn No. 1 beds are generally responsive to upgrading by washing to produce a low-ash and low-sulfur clean coal for metallurgical use. The fine crushing of samples and float-and-sink testing indicated that Knott County coals show little improvement in the release of sulfur by crushing.

Coal for Electrodes

If suitable beneficiation methods are developed, there is a potential market within the next year or two for 1-1/2 million tons of high-purity carbon from coal for electrodes in the aluminum-reduction industry. At present anthracite supplies some of the material for the cathodes or pot linings, which have a life of about 3 years. The real carbon consumer, however, is the short-lived anode. Anodes for American aluminum-reduction cells now generally are made from calcined petroleum coke bound with coal-tar pitch. Progress has been made toward beneficiating coal sufficiently to enable it to replace petroleum coke. Coke and char which contain less ash than petroleum coke,74/ have been made in the laboratory. Three methods of ash reduction have been employed: (1) Separation at low-density by the dense-medium or float-and-sink process; (2) removal of the ash-forming material by dissolving it in acid or alkaline solutions; (3) putting the coal substance into a solution to effect separation of the undissolved ash-forming material.

Coals from 10 mines in 5 States, varying in rank from semianthracite to subbituminous, have been examined. None of the coals contained a fraction low enough in ash content to permit processing by the first method alone; but, by using this method and applying the second method to the float fraction, ash contents were obtained in the finished product ranging from 1.6 to 0.18 percent. Combining the first and third methods, by dissolving the coal from the first method in a distillation fraction obtained from heavy-residue creosote and removing the undissolved ash-forming materials in a centrifuge, gave ash contents as low as 0.20 in the coal or 0.28 in the coke. So far, research has shown that this method is generally more attractive than the acid-alkaline leaching procedure. It has indicated the desirability of constructing a small pilot plant to investigate the process further, especially to produce enough superclean coal for industrial trials.

Preparation of Lignite

A study of size reduction of lignite has included investigation of power requirements of commercial-size crushing equipment, found to be in the order of 0.10

74/ Campbell, R. J., Jr., Boyd, C. L., Hilton, R. J., Coal For Electrodes; What the Market Is in the Aluminum Industry and What Can Be Done to Make Coal Suitable for It: Coal Age, vol. 58, No. 8, August 1953, pp. 86-87.

kw.-hr. per ton, operating at reduction ratios of 2.0 to 2.5. A survey of the preparation and mining practices of the major producing mines is in progress.

Variation in Hardgrove grindability indexes and the factors that influence the grindability have been determined for a variety of lignites. A significant range of grindability has been found to occur in lignites, and a major factor appears to be moisture content. In studying the variation in grindability index as moisture content was decreased, the index was found to be greatest at the higher natural moisture content, decreasing to a minimum in the midmoisture (20 to 25 percent) range and again increasing at lower moisture content. The grindability index also was found to vary with different vertical increments within a single bed, and the relation of this variation to petrographic data is being investigated.

Drying Low-Rank Coals

During the reporting period, significant accomplishments were made in commercial application of drying processes developed by the Bureau, in cooperation with industry. A prototype drier plant, designed by Bureau engineers for the Texas Power & Light Co. and Aluminum Co. of America, was operated several months at Rockdale, Tex., to prove and test engineering and design features. By November 1952 about 35,000 tons of lignite had been dried in this plant under various conditions, and a dried product suitable for direct combustion in a slagging-type furnace was prepared from Texas lignite, which in the raw state contained about 36 percent of natural bed moisture. The dried lignite contained about 3.5 percent moisture and had a heating value of about 10,000 B.t.u. per pound.

Following these successful demonstrations, Bureau engineers cooperated with the Texas Power & Light Co., Aluminum Company of America, and several engineering contractors such as EBASCO, Koppers Co., Silver Engineering Works, and Rust Engineering Co., on the design of a battery of 9 of these "Parry" driers to serve a 240,000-kw. power plant, which is integrated with the ALCOA reduction plant at Rockdale, Tex. The driers were built during 1953, and 3 units were operated successfully in December 1953 to furnish dried lignite for one 80,000-kw. steam generator.

A report was published[75] covering drying and carbonization research conducted at the Denver laboratories under cooperative agreement between the Bureau of Mines and Texas Power & Light Co., which led to the commercial development at Rockdale. A variety of coals, ranging in rank from lignite through high-volatile bituminous, were tested in the pilot plants using the entrained and fluidized technique. The primary purpose of these investigations was to determine the feasibility of drying high-inherent-moisture, noncaking coals and producing char or carbonized residue suitable for power-plant fuel. Two pilot-plant units were constructed and used in Denver, and the diagram of the smaller one, 5-ton-per-day capacity, is shown in figure 13. The first step in processing is to dry the crushed, high-moisture coals in an entrained-state dryer. It consists primarily in feeding the minus- 1/4-inch coal into a stream of high-temperature gas. This gas, produced in a conventional combustion chamber, is supplied to the drier at temperatures ranging from 1,700° to 2,500° F., and serves to move the coal through the drier while supplying the heat required for drying the coal. The heat is transferred very rapidly from the gas to the coal under this condition, and the products leave the system at about 300° F. The only measurable effects of drying are: (1) Removal of moisture from the coal with a

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[75] Parry, V. F., Landers, W. S., Wagner, E. O., Goodman, J. B., and Lammers, G. C., Drying and Carbonizing Fine Coal in Entrained and Fluidized State: Bureau of Mines Rept. of Investigations 4954, 1953, 43 pp.

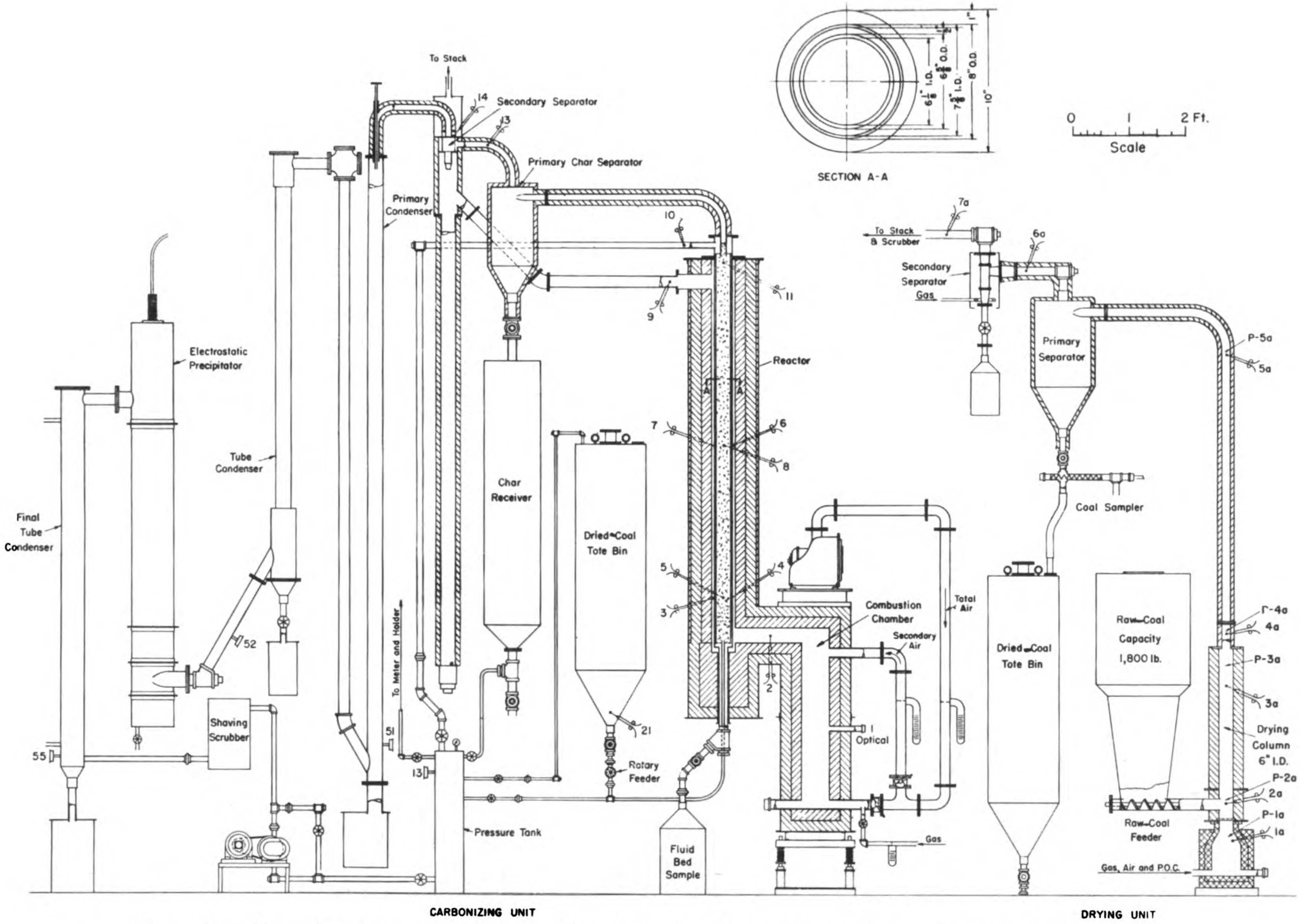

Figure 13. - Pilot plant for drying and fluidized carbonization of noncoking coal–capacity 250 to 300 lb. per hr.
Bureau of Mines, Region IV, Denver, Colo.

corresponding increase in its unit heating value; (2) preheating the coal; and (3) degradation of coal particles owing to slacking or attrition. Fine, dried coal leaving the drier is separated from the gas stream in cyclone separators and then fed pneumatically to the fluidized carbonizer. The carbonizing technique and results are discussed in the carbonization section of this report.

Four Parry driers designed to remove surface moisture from bituminous coal have been operating in Canada.[76] These units are drying coal as large as 2-1/2 inches and removing up to 25 percent surface moisture from washery slurries. These dryers are based upon the design used in the pilot plant at Denver, incorporating improvements developed in the field at West Canadian Collieries, Blairmore, Alberta, Canada. When drying large coal in these driers, 1-1/2-inch by 0 coal is carried out over the top in the entrained state, and the larger coal falls to the base of the dryer and is removed mechanically. Drying of both sizes can be controlled by adjusting the velocity of gases in the drier column. Although these driers were originally designed to handle 50 tons per hour, in actual operation they are handling up to 100 tons of coal per hour, depending upon the moisture content.

Briquetting Low-Temperature Char

Various areas of the world, such as Mexico, Thailand, and India, are facing shortages of charcoal, or increased costs, because of the destruction of forests near the population centers. These areas also have appreciable deposits of low-rank fuels, either lignites or subbituminous coals, and these countries are interested in adapting these fuels for use in place of charcoal. Production of briquets from the raw, high-moisture coals is not feasible because of the slacking and degradation that occurs as the moisture evaporates, and the reactivity of such briquets is less than that of charcoal. Low-temperature chars made from the low-rank fuels are very reactive, burn with little odor, and contain no free moisture, and, if briquetted with suitable binders could serve as charcoal substitutes.

The briquetting properties of low-temperature chars prepared from several coals were investigated.[77] These included lignite from Texas, subbituminous C coal from Alaska, subbituminous B coal from Wyoming, and high-volatile C bituminous coal from Mexico. Chars were produced by two techniques: (1) Carbonizing the lump coal in a gas-fired, modified BM-AGA circular retort to produce lump char; and (2) carbonizing the crushed coal in the fluidized retort developed at Denver, producing fine-sized char.[78] The rate of heating of the coal was faster in the fluidized retort, resulting in incipient fusion of the subbituminous coals. The fluidized chars from these coals produced at about 900° F., did not agglomerate, but appeared to consist of cenospheres resulting from the fusion of the individual coal particles. The lump chars from these same coals did not show any indication of fusion, because of the slower heating rate.

Satisfactory briquets were produced in a roll press from all of the lump chars, using either pitch or spent sulfite liquor as the binder. Fluidized char from the lignite and the bituminous coal could also be briquetted by this technique. The char obtained by the fluidized carbonization of the subbituminous coals, however, could not be successfully briquetted. It was concluded that the weak cell walls of these fluidized cenospheric chars broke down during fluxing with the binder, increasing the effective surface, and requiring excessive binder, and that these chars were somewhat elastic, causing an expansion and cracking of the briquets when the roll pressure was released.

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[76] Morrison, R. L., and Grant, P. S., The Parry Dryer: Proc. Third Biennial Briquetting Conf., Univ. of Wyoming Natural Resources Research Inst., Inf. Circ. 6, November 1953, pp. 30-37.

[77] Landers, W. S., and Parry, V. F., Briquetting Properties of Fluidized Chars: Proc. 3d Biennial Briquetting Conf., Univ. of Wyoming, Natural Resources Research Inst., Inf. Circ. 6, November 1953, pp. 37-47. Pres. 3d Biennial Briquetting Conf., Banff, Alberta, Canada, Aug. 31, 1953.

[78] See footnote 75.

UTILIZATION OF COAL AND OTHER FUELS FOR COMBUSTION

Combustion of Anthracite

Anthracite Laboratory Investigations

To aid in developing markets for anthracite, the Anthracite Research Laboratory at Schuylkill Haven, Pa., conducted studies of available economic and technical information relating to use of fuels for frost control and crop drying. Also, since the laboratory was occupied early in 1950, the stoker-boiler units for heating the laboratory have been studied while operating. Figure 14 shows the operating floor and control panel for these units. Reports covering these studies are being prepared.

The Anthratube

At the request of various Government agencies, a series of comprehensive tests[79] were made to obtain performance data on a new type of automatic anthracite-burning heater to use Pea or No. 1 Buckwheat anthracite, which is called the Anthratube (fig. 15). This unit has possibilities of economical application for service hot-water supply and in small Government buildings for space heating. The unit, which is also suitable for domestic use, was found to be rugged, easy to maintain, and remarkably free from operating difficulties. Very little chimney draft was required since an integral fan supplied most of the pressure differential needed; power requirements varied with the size of fuel used and the season of the year, averaging from 34 to 54 kw.-hr. per ton of coal. Pea and Buckwheat gave equally satisfactory house service results, but Buckwheat would not feed when it was excessively wet. The B.t.u.-per-hour capacity was approximately 8 percent less with Buckwheat than with Pea. The efficiency was about 81.6 percent for Pea coal and about 84 percent for Buckwheat when operating continuously, but was much lower during off periods. Since the unit operated on cycles of on-and-off, the average annual efficiency varied with the ratio of time on to time off.

Fuel-Engineering Service

Consulting and field testing services were continued in this country and Alaska to aid Federal agencies in selecting, testing, and using fuel and fuel-burning equipment and in the economical use of steam. At the request of the Department of the Navy, a survey was made of the plant equipment and operation at the Naval Powder Factory, Indianhead, Md., which resulted in recommended changes that improved operation. At the request of the Department of Justice, a new boiler plant at the Federal Penitentiary, Leavenworth, Kans., was tested for contract requirements and tuned up to give best operating results. At the request of the Bureau of Indian Affairs,

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[79] Barkley, J. F., Burdick, L. R., and Morgan, R. E., Tests of the Anthratube: Bureau of Mines Rept. of Investigations 4936, 1953, 13 pp.

Original from THE OHIO STATE UNIVERSITY

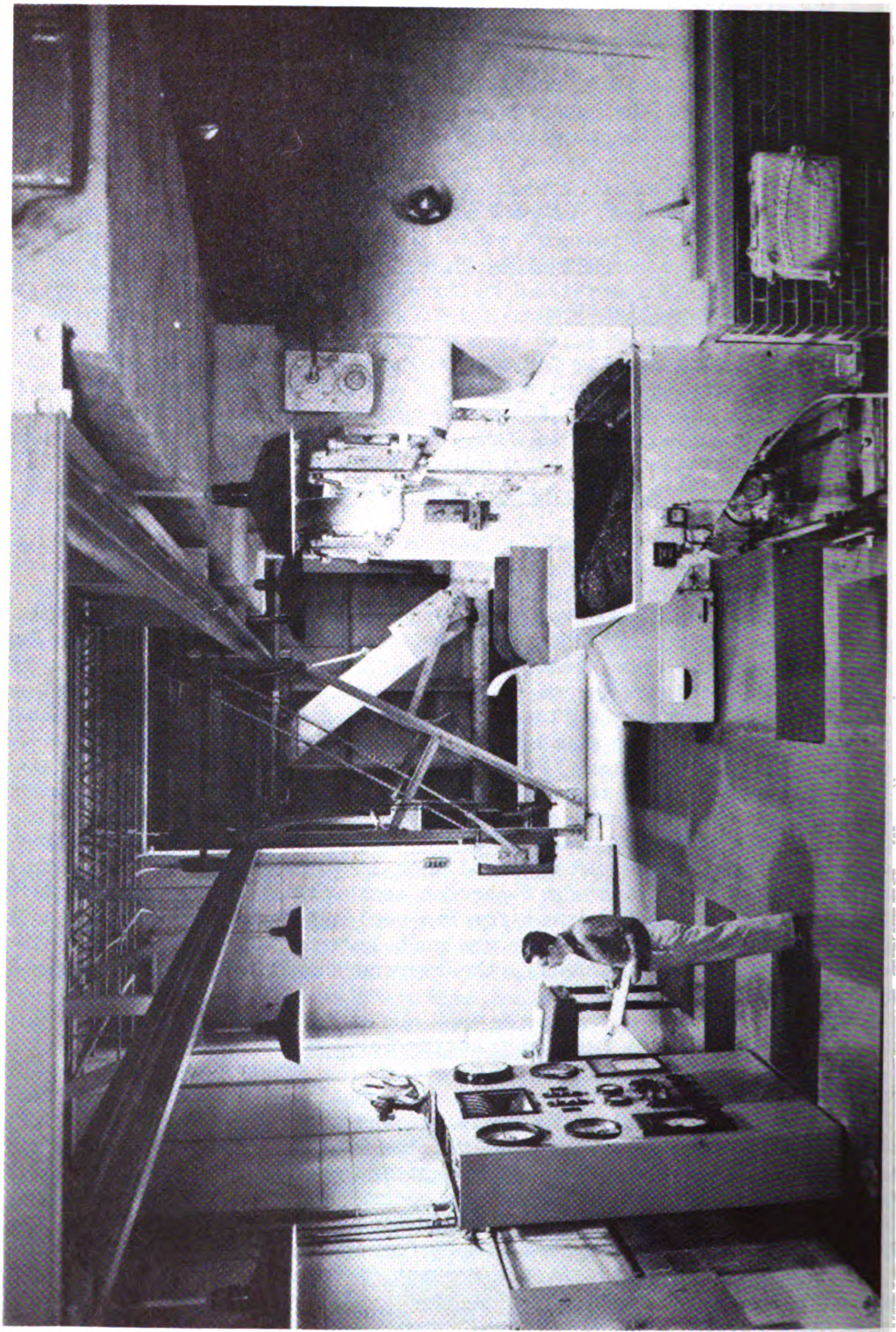

Figure 14. - Anthracite Research Laboratory, experimental boiler room.

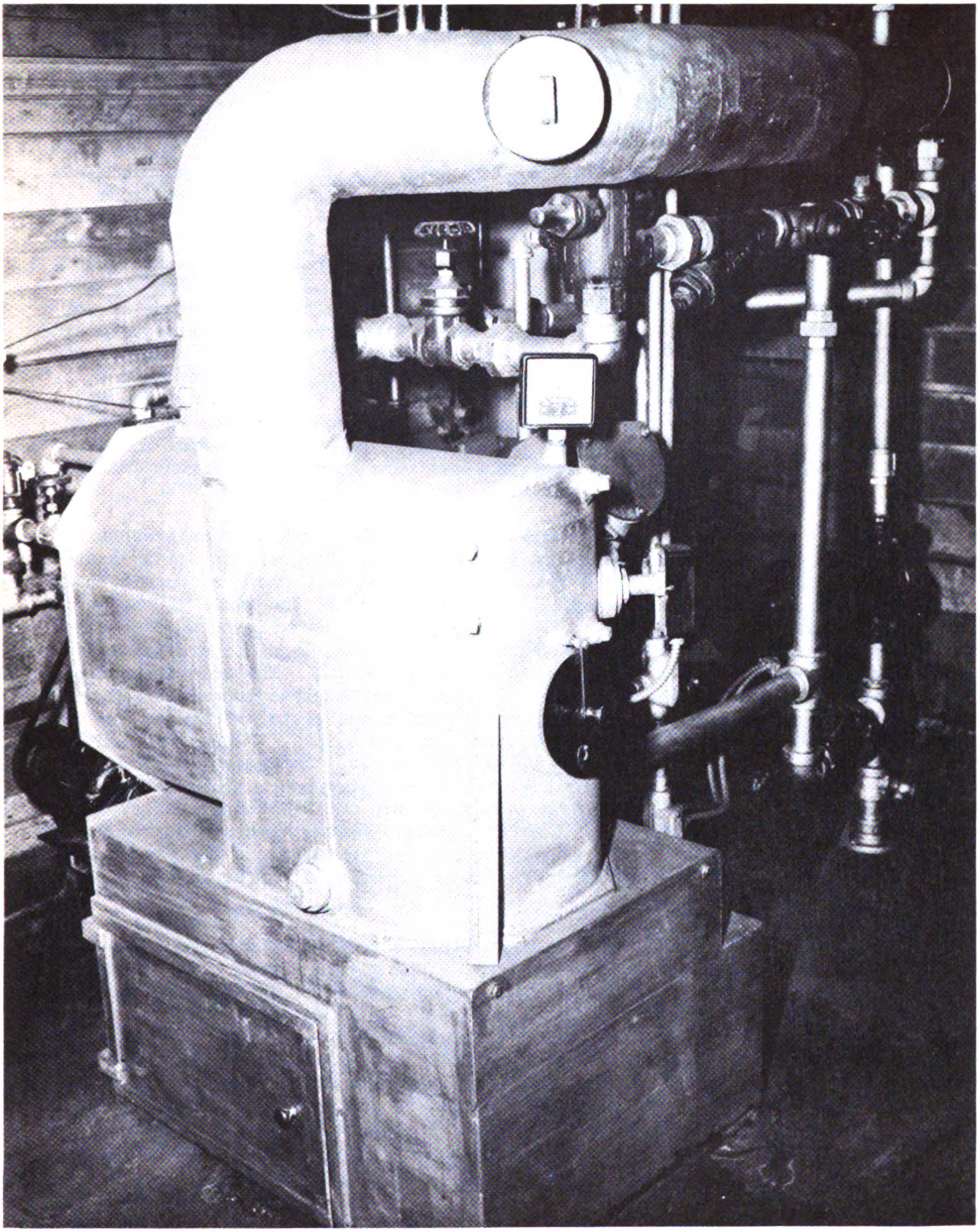

Figure 15. - View of front and side of Anthratube.

acceptance tests were made of boiler and turbine-generator equipment of a new power plant of the Hopi Indian Agency, Keams Canyon, Ariz., which resulted in equipment changes and more efficient operation.

A survey of principal fuel-burning plants in the Philippines was made for the Foreign Operations Administration to determine the possibilities of their burning Philippine coal. At the request of the Department of the Air Force, a survey was made of a new power plant at Eielson Air Force Base, Alaska, to give technical assistance regarding acceptance testing and operation of boiler and turbine room equipment. A survey was made of the power plant of Andrews Air Field, near Washington, D. C., for the Department of the Air Force, resulting in determination of the operating difficulties and in recommendations as to the type of coal to use. At the request of the Department of Justice, a survey was made of the power plant of the Federal Penitentiary at McNeil Island, Wash., resulting in recommendations as to different operating procedures and feeding chemicals to prevent excessive corrosion, thereby eliminating the need for early replacement of boilers. At the request of the Bureau of Yards and Docks, Department of the Navy, acceptance tests of new boiler equipment were witnessed at the new Naval Ordnance Plant, Louisville, Ky., resulting in recommended changes in equipment. At the request of the Veterans Administration, cost analyses were made to determine proper choice of fuel for eight projects. Services on 292 other special problems were given 62 different Federal agencies.

Cooperative work with the Air Preheater Corp. of New York City on preventing deposits and corrosion in air preheaters was continued. Progress in air preheater design demands that the temperature of the exit flue gases be lowered considerably below those now obtained, since lowering the temperature of the gases is one remaining avenue to improved fuel efficiency. This objective, however, must be obtained without excessive corrosion of heating surfaces. The results of several years research work on regenerative air preheaters was published.[80] The relative corrosion rate and the corrosion distribution of 38 different metal plate materials, 22 different coatings on metal, and 6 ceramic and miscellaneous plate materials were determined in field tests under regular plant-operating conditions. Figures 16 and 17 show the relative corrosion rates for the various metals. In general, all metals that form sulfates cannot be used for air preheater plates without some corrosion and eventual plate failure. None of the coatings gave satisfactory results, except Pyroenamel on enameling-grade steel. Certain ceramic plates were not corroded. It was shown that many factors, such as temperature, gas composition, the presence of deposits and their composition, as well as plate composition, affected corrosion losses.

Various relatively simple types of laboratory corrosion tests were devised in the general study to develop a short test that would give the same relative corrosion rates for different metals as found in the air preheater. Although this problem was not satisfactorily solved, considerable general or basic consistency in the duplication was obtained with certain tests. Considerable information also was obtained on the extent and composition of deposit accumulations and the mechanism of deposit buildup. The work indicated several promising lines for further investigation, which will be followed, such as the use of plate materials not attacked by sulfuric acid, prevention of the formation of SO_3 in the flue gases, removal of dust from the flue gases ahead of the air preheater, and more efficient methods of deposit removal.

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[80] Barkley, J. F., Karlsson, Hilmer, Berk, A. A., Stark, C. F., and Burdick, L. R., Corrosion and Deposits in Regenerative Air Preheaters: Bureau of Mines Rept. of Investigations 4996, 1953, 23 pp.

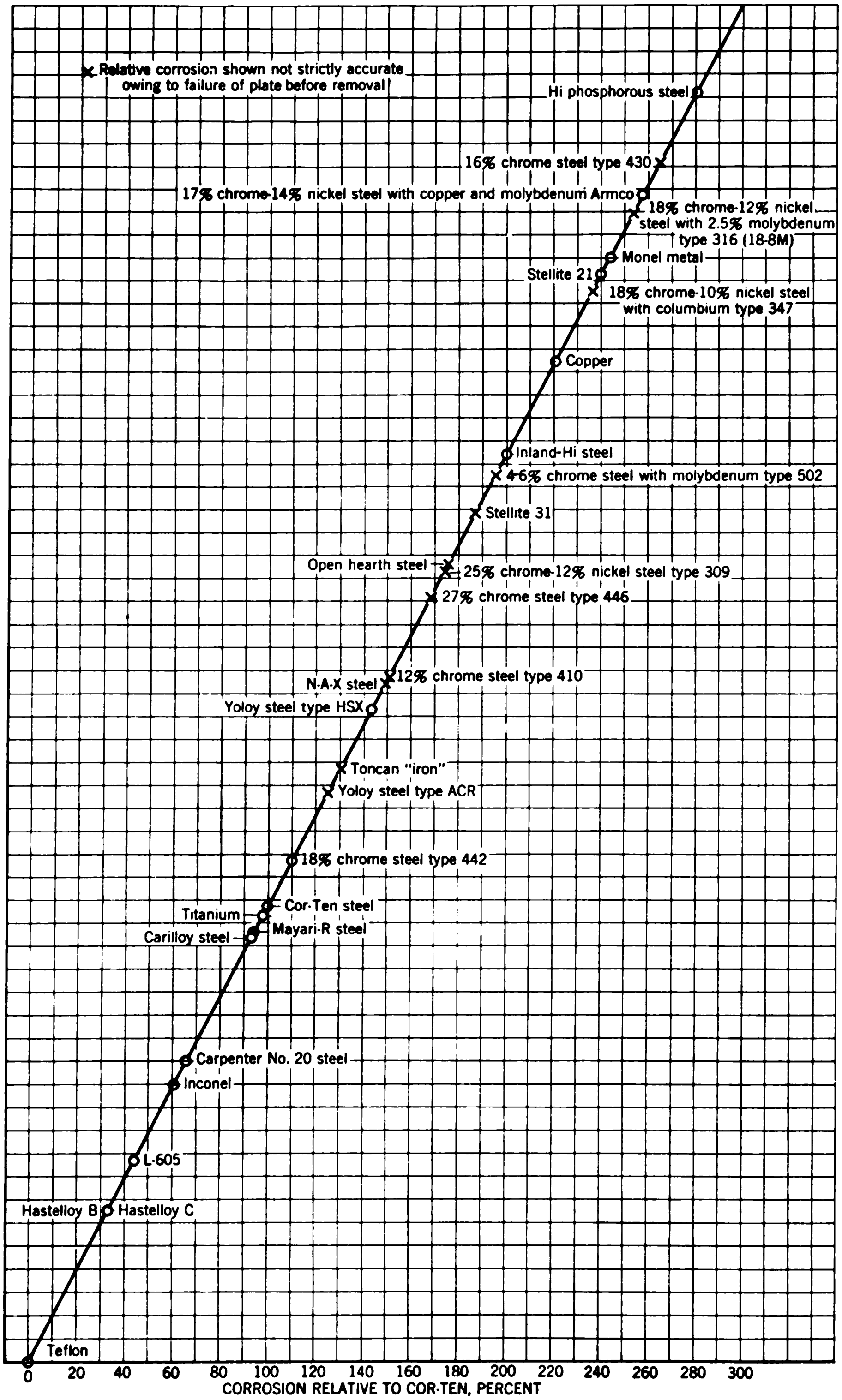

Figure 16. - Corrosion rate in Harding Street Station air preheater of various materials relative to that of Cor-Ten steel.

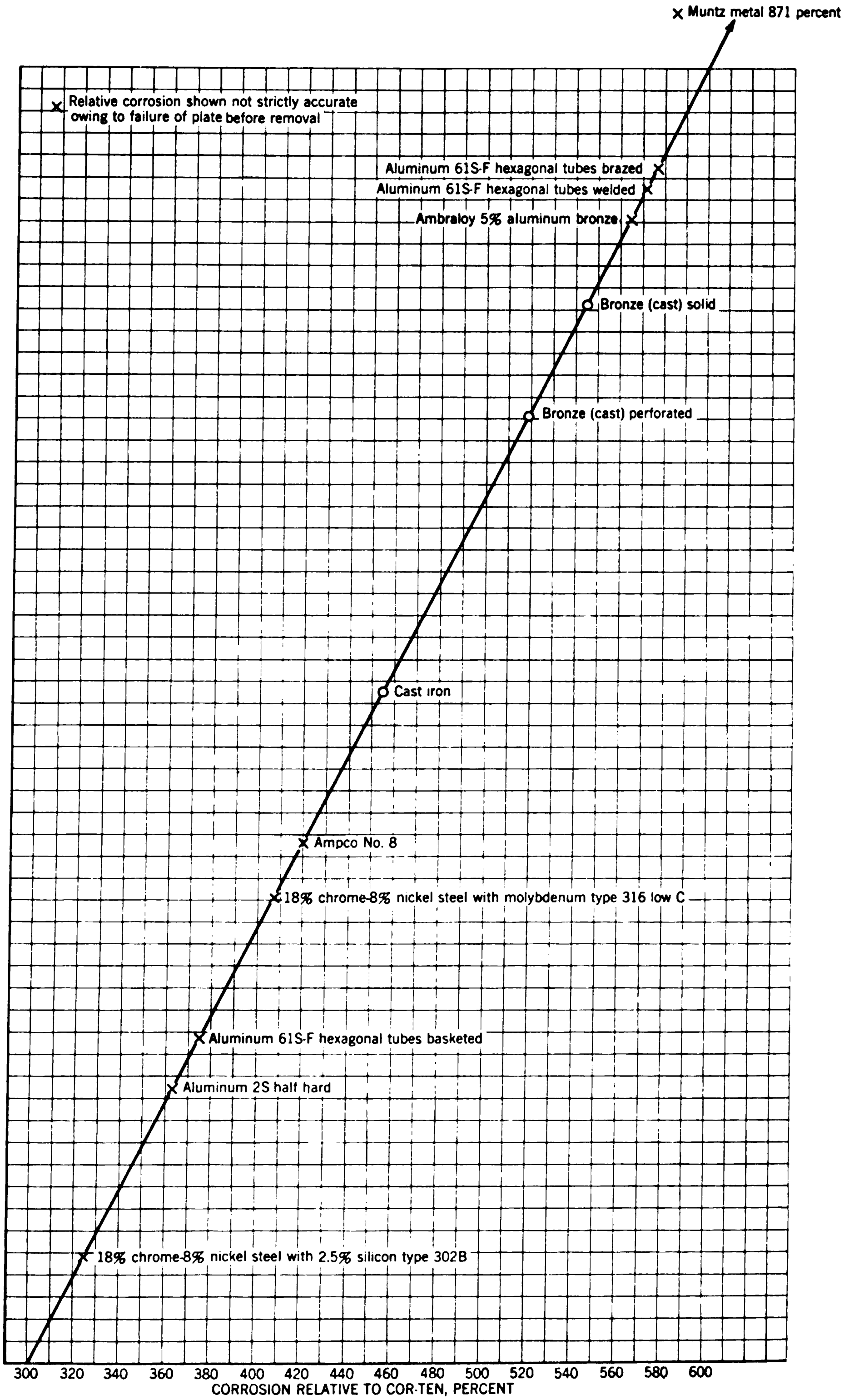

Figure 17. - Corrosion rate in Harding Street Station air preheater of various materials relative to that of Cor-Ten steel.

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Some of the research findings were included in a discussion of a paper[81/] on air preheater design read before the American Society of Mechanical Engineers. Based on interviews with various research workers of Great Britain, a report[82/] on air preheaters was made to the Research Committee on Low-Temperature Flue-Gas Corrosion and Deposits of the American Society of Mechanical Engineers.

Factors Affecting Heat Absorption in Furnaces

In cooperation with the Louisiana Power & Light Co. and the Research Department of Combustion Engineering-Superheater, Inc., an investigation[83/] was made of the distribution of heat absorption in a natural-gas-fired, water-cooled, steam-boiler furnace. The purpose was to augment and expand knowledge concerning the combustion of natural gas in boiler furnaces and heat transfer from nonluminous flames, in view of the rapid expansion of the use of natural gas for steam generation.

Four series of tests, comprising 14 complete runs, were made on a boiler at the Sterlington Steam Electric Station of the Louisiana Power & Light Co., at Sterlington, La. These tests, made at 1/4, 1/2, 3/4, and full load and at low, medium, and high excess-air values, were designed to determine the relative heat absorption by the four walls, and the progress of combustion as affected by load, excess air, and location of burners in service.

The use of a fuel free of ash revealed important factors in furnace performance because ash was not present to mask the influence of such factors, as was the case in previous investigations on pulverized-coal-fired furnaces. The results showed: (1) That the shape of the flame envelope (invisible with natural gas) was independent of load; (2) that about 80 percent of the heat absorbed by the furnace was transferred by radiation; (3) that with enough pressure of preheated air and with a well-designed mixing burner, natural gas can be burned rapidly and completely at high heat-release rates (approximately 160,000 B.t.u. per cu. ft.); and (4) that the arrangement permitting the longest flame travel is the best from the standpoint of minimizing the effect of excess air on furnace efficiency.

Furnace heat absorption was measured in a spreader-stoker-fired boiler furnace at Carbide and Carbon Chemicals Co., Whiting, Ind., in cooperation with the ASME Furnace Performance Factors Committee.[84/] Fifteen tests were made to determine the effect on furnace-heat absorption of variations in load, excess air, the percentage of combustion air admitted over the fuel bed, overfire air temperature, and slag and ash deposits.

The results of these tests showed that the maximum furnace-heat-absorption efficiency, when corrected for slag and ash deposits, was 61.3 percent at low load,

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[81/] Barkley, J. F., Discussion of paper by Hilmer Karlsson and William E. Hammond, Air Preheater Design as Affected by Fuel Characteristics: Trans. ASME, vol. 75, No. 5, July 1953, pp. 718-719.

[82/] Berk, A. A., Work in Great Britain on Corrosion and Deposits in Air Preheaters: Mech. Eng., vol. 75, No. 7, July 1953, pp. 545-546.

[83/] Mumford, A. R., and Corey, R. C., Variation in Heat Absorption in a Natural-Gas-Fired, Water-Cooled Steam-Boiler Furnace: Trans. ASME, vol. 74, No. 7, October 1952, p. 1191-1215.

[84/] Myers, J. W., and Corey, R. C., Furnace Heat Absorption in a Spreader-Stoker-Fired Steam Generator. I. - Furnace Heat-Absorption Efficiency as Shown by Enthalpy of Gases Leaving the Furnace: Trans. ASME, vol. 75, No. 5, July 1953, p. 909.

with 27 percent excess air, and with 16.7 percent of the air introduced over the fuel bed. The lowest efficiency, 48.1 percent, was obtained at intermediate load, with 53 percent excess air, and with 14.7 percent of the air admitted as overfire air.

Utilization of Low-Grade Coals

Owing to a gradual decline in the quality of coal as mined, rising coal costs, and the desirability of conserving the best quality coals for chemical and metallurgical purposes, the need for greater use of low-grade coals for generating power and heat is receiving increased attention by power engineers and furnace designers. Accordingly, a study[85/] [86/] was made of the utilization of low-grade coals in boiler furnaces, with special attention to the effects on overall boiler performance of ash content, ash fusibility, coal-swelling properties, sulfur content, moisture, and grindability. In this country, coal with ash exceeding about 20 percent generally is considered to be of inferior quality.

In the United States, large steam generators, delivering up to 1.5 million pounds of steam per hour, are preferred for central stations. With certain modification in design, the dry-bottom pulverized-coal-fired furnace, which is predominant in this field, will burn nearly any kind of low-grade coal satisfactorily; and the cyclone burner, which is a relatively recent development, will also perform well with high-ash coals, provided certain limitations on volatile matter and ash fusibility are observed. For smaller plants with capacities up to about 250,000 pounds of steam per hour, the traveling grate and the continuous-discharge spreader stoker are favored. The former are used to burn low-grade anthracite, coke breeze, and bituminous coals with a free-swelling index not exceeding 6, and the latter is favored for the lower rank coals and medium- and high-volatile caking coals. From this study it was concluded that low-grade coals may be burned more widely than is the case now in conventional boiler equipment; however, considerable research must be conducted on the heat-transfer properties of luminous flames and on the physical properties of coal ash before the many problems incurred by burning low-grade coals are solved.

In this connection, a project was initiated recently to determine the feasibility of burning the refuse from washeries and preparation plants on a chain-grate stoker to make lightweight aggregate for concrete, but no reports are available on this project.

Disposal of Radioactive Wastes by Incineration

In connection with developing incinerators for disposing of combustible wastes contaminated with low-level radioisotopes, the Federal Bureau of Mines, in cooperation with the U. S. Atomic Energy Commission, has conducted an experimental investigation with a model incinerator for burning low-ash, high-volatile, combustible material.[87/] The primary objective was to obtain data for the design of units of

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[85/] Corey, R. C., and Myers, J. W., Utilization of Low-Grade Coals for Power Generation: Combustion, vol. 24, No. 3, September 1952, pp. 43-48.

[86/] Corey, R. C., and Myers, J. W., Utilisation des Charbons de Faible Valeur pour la Production de l'Energie aux Etats-Unis d'Amerique: Ann. mines Belg., vol. 51, No. 6, November 1952, pp. 780-799.

[87/] Corey, R. C., Spano, L A., Schwartz, C. H., and Perry, H., Experimental Study of Effects of Tangential Overfire Air on the Incineration of Combustible Wastes: Air Repair, vol. 3, No. 2, November 1953, pp. 109-116.

any desired size to consume such materials with maximum combustion efficiency and retention of particulate matter, consistent with reasonable burning capacity and air-to-fuel ratio. A schematic diagram of the test equipment is shown in figure 18.

Using sawdust as a fuel and only tangential overfire air, it was found that the burning rate and the discharge of smoke, tars, and other products of incomplete combustion can be related to dimensionless factors (Reynolds number) of the air in the tangential ports, and to a smaller extent, upon the location of the ports with respect to the surface of the charge. From the standpoint of minimum discharge of unburned products, optimum performance was attained in the model incinerator when using only overfire air, under the following average conditions: A burning rate of about 6 pounds (hr.) (ft.^{2}) of grate area, excess air of 50 percent, and a Reynolds number of the air through the tangential ports of 15,000-20,000.

Tests of Army Stoves and Cookers

A cooperative investigation to evaluate the performance of heating equipment of the Office of the Quartermaster General was continued, with the scope of the work extended to include development of several items. An experimental fire unit (complete cooking unit, including burner and all auxiliary parts) for cooking stoves was tested to determine its stability and operational hazards, and it was found that this unit was unsatisfactory in these respects. It was recommended that additional work be carried out before the unit is released for field testing.

A standard test procedure was established for evaluating the overall performance of immersion water heaters, and six units were tested. The test results disclosed that the heating capacity of these units varies from 14,000 to 37,600 B.t.u. per hour. It was found that by shielding the burner with a metal sleeve, thereby preventing the burner flames from impinging on the water-cooled surfaces of the heater, the burning capacity could be increased 43 percent. In addition, a method of igniting the burners that reduced flashback hazards, was developed.

An investigation was initiated recently to develop effective spark arresters for solid-fuel-burning stoves to improve safety conditions when the stoves are used in tents constructed of flammable material. Although a number of special reports have been submitted to the Office of the Quartermaster General, it is unlikely that any of the information will be published because the work is carried out on contracts with that agency.

OTHER INVESTIGATIONS RELATED TO FUEL UTILIZATION

Tests of a Heat Pump for Domestic Heating and Cooling

Data were published on the installation and several years operation of a packaged-unit heat pump installation in a residence near Washington, D. C.[88] The major conclusions from this study were that: The heat pump, as the result of many years development of similar commercial air-conditioning equipment, has been developed to provide entirely satisfactory heating and comfort cooling, if properly installed; it provides heat at lower temperatures than conventional fuel-fired air-circulating systems and therefore is believed to give better overall heat distribution in the heated area, and less "on-and-off" temperature variation; the unit is relatively expensive

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[88] Carman, E. P., Tests of a Heat Pump for Domestic Heating and Cooling: Bureau of Mines Rept. of Investigations 4977, 1953, 31 pp.

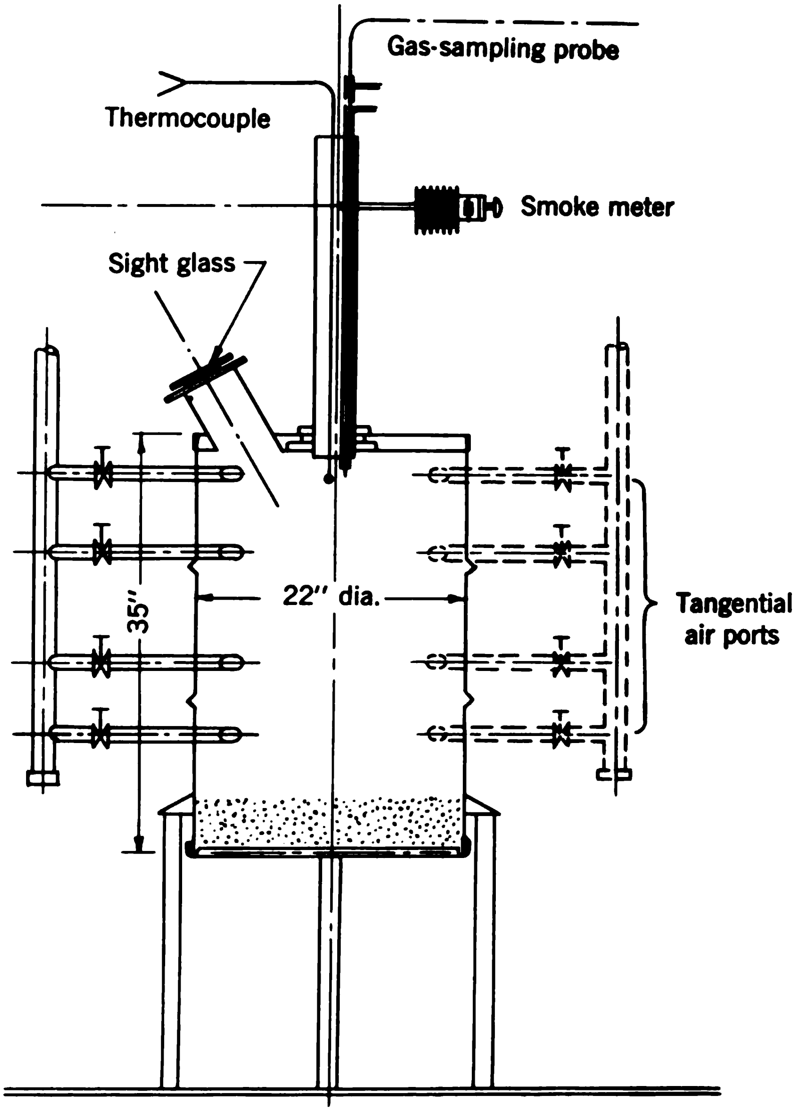

Figure 18. - Schematic diagram of model incinerator.

to install but provides both winter heat and refrigeration comfort cooling for summer and will generally be found less expensive to install than conventional heating units with attached refrigeration cooling units; space requirements for the unit are less than for most conventional heater-cooler combinations; noise of operation is no greater than many fuel-fired systems and is not considered a disadvantage of the system; cost of electricity for operation, the only cost except maintenance, was just slightly higher than would have been the cost of heating with natural gas, oil, or anthracite, at prices prevailing in the Washington area at the time; maintenance costs were high when averaged over the entire period studied, but were very nominal for the first 5 years and in the later years involved somewhat unusual expenses that might not be considered typical.

Flow Properties of Fine Powders

The Army Chemical Corps requested the Bureau to utilize its previous experience in fluid-solid systems, such as fluidized transportation and drying of coals, in a study of the basic factors involved in the pneumatic transport of fine powders. This involved evaluation of numerous factors, including: Dimensions of the transport system; physical properties such as viscosity and density of any fluid that may be used; and density, shape, size, and concentration of the solid matter. Work to date has included a literature survey, development of methods for the measurement of size and size distribution of various fine powders, and semiquantitative investigations into the flow of air suspensions of particles through vertical and horizontal pipes. It is unlikely that specific results of the laboratory investigation will be published because the work is conducted for national defense; however, as an incidental phase of this work, a paper on fluid dynamics was published.89/ This paper was a review of the literature on fluid dynamics that had been published during 1951 and 1952, including reference to 299 articles on the subject.

Germanium From Coal

An investigation was conducted in cooperation with the U. S. Army Signal Corps Engineering Laboratories to determine the occurrences and distribution of germanium in the stoker ash and fly ash from coal-fired steam-generating boilers. It was found that most of the germanium in the coal fired in slag-tap and dry-bottom pulverized-coal-fired boilers and in underfeed and traveling-grate-fired furnaces leaves the boiler associated with the fly ash. A report on this study is expected to be published at a later date.

Boiler Feed-Water Conditioning

Analyses and resulting recommendations were made on 17,474 samples of boiler water. Of these, over 70 percent were for the Department of National Defense, 17 percent for the Veterans Administration, and the remainder for other agencies of the Government. Reports and recommendations were made covering 15 analyses of various boiler plant scales and deposits, 20 miscellaneous special water analyses, and one analysis of a boiler compound.

A total of 1,441 special Bureau of Mines Field water-test kits, 25,487 bottles of chemical reagents, and 35,194 test-kit replacement parts were distributed to various Government agencies. Distributing these kits and reagents from a central source without use of formal purchase orders and individual order reimbursement saved the Federal Government an estimated $84,000 for the 18 month period, as compared to open market purchases.

89/ Weintraub, M., Leva, M., Fluid Dynamics: Ind. Eng. Chem., vol. 45, No. 1, January 1953, pp. 74-82.

Difficulties in 7 heating plants and 2 other water-using installations operated by various Federal agencies in the local area of the District of Columbia were investigated. Advice was supplied on boiler-water treatment, boiler-water testing, inspection of boilers for scale and sludge, control of return-line corrosion, and installation of return-line corrosion testers.

Advice and assistance were given several Federal departments and bureaus on boiler-water problems and means of alleviating them. These services were extended to the Departments of the Air Force, Army, Justice, Navy, and Post Office, the Bureau of Indian Affairs, Federal Supply Service, General Services Administration, National Institute of Health, National Zoological Park, D. C., and Veterans Administration. They included such services as instruction in proper methods of water testing, testing to determine amount of return-line corrosion, estimation of and treatment for dissolved solids of boiler water, advising on applicability of filming amines for return-line corrosion, protecting idle boilers, controlling steam purity, controlling corrosion in high and low-pressure boilers and in return lines, using various organic compounds as sludge conditioner, on control of carbon dioxide content of steam, identifying condensate contamination, using external water softeners and antifoams to prevent boiler-water carryover, and many related problems.

An instruction booklet[90] was written for use by boiler-plant engineers in installing the Bureau of Mines return-line corrosion tester. At the request of the Bureau of Yards and Docks, Department of the Navy, two chapters for a Navy publication, entitled "Power-Plant Water Conditioning," were reviewed and suggestions made for correction and revision.

The total number of plants receiving consulting service and advice increased about 13 percent during this reporting period. On the basis of savings reported by representative plants and assuming similar savings in all the plants, a total saving of about $30,000,000 a year is being achieved by Government agencies through this program; this is approximately equal to the total appropriations for the entire Bureau of Mines for the fiscal year 1953.

Boiler Water Research

Prevention of corrosion in piping returning condensed steam to the boiler plant continues to be a principal service need to Government-operated heating and power plants. Laboratory research on more effective and less expensive chemical treatments of steam and boiler feedwater has shown how many such problems can be solved with maximum economy and optimum effectiveness. Field tests run in conjunction with this laboratory work have indicated whether or not chemical treatment was desirable and have shown that the rate of pipe deterioration in the operating systems was negligible when proper chemical treatment was used.

The most applicable chemical treatment for Federal plants is the use of amines, that is, volatile, alkaline materials related to ammonia. Industry, guided by the results of this work, has also discovered the practical corrosion-preventive benefits of protecting very costly central-station power-generating boiler plants with ammonia and the amines. Low concentrations of ammonia or cyclohexylamine are being used in many such plants to protect feed pumps, stage heaters, economizers, condensers and piping. Morpholine is also increasingly used for this purpose and, in addition, this amine has been shown to protect turbine metal at the region of initial saturation of the steam.

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[90] Instructions for Use of Bureau of Mines Return-Line Corrosion Tester: BWS 22, December 1952.

The principal factor contributing to condensate return-line corrosion in Government-operated plants is the carbon dioxide content of the steam that forms corrosive carbonic acid in the condensate. In a discussion of a paper presented at a national water conference,[91/] it was shown that a very large percentage of the carbonate impurities in boiler feedwater is decomposed to carbon dioxide in the boiler and that this carbon dioxide then becomes an impurity of the steam.

British engineers and scientists appealed for advice from this country concerning measures to be taken to prevent caustic cracking of boiler seams: Accordingly, a paper[92/] was presented to the Corrosion Group of the Society of Chemical Industry, in which it was shown that research on boiler-seam cracking, begun at the Bureau some 20 years ago, identified the major factors contributing to intercrystalline cracking and led to the design of the embrittlement detector, the basic tester for a laboratory study. Several effective water-conditioning treatments were developed for use over the range of operation pressures at which cracking may be a problem. Simultaneously, embrittlement detectors were installed on stationary and locomotive boilers to measure the tendency for the concentrated boiler water to cause cracking, and study of these frequently led to trials of methods of treatment proposed by the Bureau of Mines.

There is now a large background of data to show that nitrate, quebracho-tannin, and zero-caustic treatments have been applied successfully to prevent cracking of embrittlement detector specimens. There is also an increasing record of parallelism between the results of testing with the embrittlement detector and experience with operating boilers. The treatment of principal usefulness is the one in which sodium nitrate is added to the boiler feedwater in proportion to the alkalinity developed when this feedwater is concentrated by the generation of steam in the boiler. Over a recent 2-year period, reported applications of chemical treatment to prevent cracking used sodium nitrate predominantly. Nevertheless, several cases of intercrystalline seam cracking are reported each year in boilers that are not treated. The fact that the number of such failures is small shows that, because of a number of contributing factors, including nitrate and other boiler-water treatments, caustic cracking in boilers is no longer a serious problem in the United States.

A chapter on analytical methods[93/] was written for the Manual on Industrial Water, an American Society of Testing Materials publication originating in its Committee D-19 on Industrial Water. The chapter offers a selection of the better methods now available for analyzing industrial water chemically, indicates which methods are superior for various purposes, discusses the procedures briefly, and refers to 68 original sources for details of those methods that are not included in an appendix as ASTM Standards and Tentatives.

Air and Steam Pollution

Mine-Refuse Fires

Investigation of the fundamental and engineering aspects of mine-refuse disposal was continued, with the first phase being concentrated on developing safe

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[91/] Berk, A. A., Discussion on Effect of Operating Pressure on Carbon Dioxide Content of Steam: Eng. Soc. Western Pennsylvania, Proc., 13th Ann. Water Conf., 1952, p. 110.

[92/] Berk, A. A., Caustic Cracking of Boilers in the United States: Chem. and Ind., 1953, pp. 360-364. (Also published in: Society of Chemical Industry Corrosion Group, Caustic Cracking in Steam Boilers, a Symposium: 1953, pp. 11-15.)

[93/] Berk, A. A., Analysis of Industrial Water: Chap. 6 in ASTM Manual on Industrial Water, 1953, pp. 79-99.

techniques for piling mine refuse. Laboratory tests were carried out in specially designed test boxes, and field tests were made in cooperation with the management of the Russellton mine of the Republic Steel Corp. Results of this work are expected to be published later.

Smoke Abatement

Smoke-abatement work throughout the United States continued to be very active. Cities requesting Bureau of Mines publications and advice included Atlanta, Ga., Bay City and Trenton, Mich., St. Joseph, Mo., Tacoma, Wash., Baltimore, Md., Matoon, Ill., Trenton, N. J., and Staten Island, Harrison, Little Falls, Ithaca, Brooklyn, and North Tonowanda, N. Y.; the counties were Harris, Tex., Arundel, Md., and McCracken, Ky. At the request of local governments in Columbus, Ohio, and New York, N. Y., and Allegheny County, Pa., a comprehensive series of tests were made on a new type of smoke-reading instrument called the SmokeScope. At the request of the Public Buildings Administration, an acceptance test was run upon a new electrostatic precipitator at the West Central Heating Station, Washington, D. C.

Air Pollution

Work on air-pollution difficulties at the International boundary line between Canada and the United States in the vicinity of the Detroit River was continued for the International Joint Commission by its Technical Advisory Board on Air Pollution, which includes a Bureau of Mines engineer as one of its three United States members. Studies included determining the amount of air pollution and its effects and means of reducing smoke from river vessels. At the request of the American Gas Association, a paper on the air-pollution problem[94] was prepared.

At the request of the Jefferson County Air-Pollution Control District, Louisville, Ky., the Bureau conducted a survey of the operations of the district and of general conditions in the city, particularly in the Rubbertown area, to evaluate objectively the scope and progress of the control program and to make such recommendations as are considered desirable to augment the operation and effectiveness of the program. It was found that, although a considerable amount of work yet needs to be done to bring atmospheric pollution under control in Louisville, satisfactory progress is being made. In general, industry is cooperating with the program and voluntary installations of pollution-control equipment have resulted in noticeable improvements. Several recommendations were made that will be of considerable benefit to the program.

The Bureau conducted an extensive investigation at the plant of the Diamond Magnesium Co., Painesville, Ohio, to determine if the discharge to the atmosphere of gases incidental to the operation of electrolytic magnesium cells might be reduced. This investigation, initiated as the result of alleged damage to field stock of nurseries adjoining the plant from the gases discharged by the plant, resulted in eight recommendations for improvement in plant operation and equipment that would effect a significant reduction in the concentration of noxious gases in the effluent from the stack gases.

A catalytic-combustion process used to destroy odors emitted from the ventilating stacks of enamel baking ovens at the Enamelstrip Corp. plant, Allentown, Pa., was investigated. The catalyst, developed by E. J. Houdry and installed by Oxy-Catalyst, Inc., completely removes, by oxidation, enamel solvent vapors, which had been causing a serious air-pollution problem. The activity of the catalyst is such that at 400° F. the solvent vapors are completely oxidized to carbon dioxide and water vapor. Calculations, made by the Bureau of Mines, of the effect of recycling the heat liberated by the combustion of the vapors show that the quantity of city gas originally consumed in baking can be reduced by 90 percent.

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[94] Barkley, J. F., The Air-Pollution Problem: Am. Gas Assoc. Proc., 34th Ann. Conv., 1952, pp. 537-542.

It is unlikely that more detailed information from the above studies will be published because interest in these problems was relatively local.

Stream Pollution

Research was continued to develop means of conserving waste materials being discharged by mining, mineral, and related industries into streams, which would also abate offensive stream pollution. Approximately 1 million equivalent tons of sulfuric acid are wasted annually as spent pickle liquor discharged to the nation's streams from the pickling of steel, which grossly pollutes streams. Where neutralization is practiced, the lime and limestone used for neutralization, as well as the acid, are wasted; lagoons containing the neutralized sludge tie up useful land, and the cost of handling the sludge is very high. Therefore, a process was proposed[95] to regenerate the free acid and to salvage for reuse the ferrous sulfate monohydrate crystallized from the spent pickle liquor. The process would be integrated with steel pickling and would increase the efficiency of steel making.

Sand and gravel plants in cities and towns very rarely have enough space for settling basins, and therefore it is common practice to discharge their waste waters to the local streams. This creates sand banks, which interfere with normal stream flows and use. More important, the turbidity of the wash waters prevents the stream's plant life from receiving sunlight for their essential life functions. Paradoxically, the sand and gravel industry buys such sand that is now being wasted. Demonstrations using a liquid cyclone were made to industrial representatives showing how the useful sand fines could be concentrated for salvaging. No report is planned covering this study, since there are manufacturers who have sold equipment to salvage sand, which equipment has been satisfactory to the users.

Pine oil is a universally used frothing agent in minerals flotation and its presence in waste water imparts a bitter taste to the receiving stream. As a first step in developing a process for decreasing to tolerable limits the concentration of pine oil in discharged waters, a colorimetric method[96] was developed for concentrations of 1 to 30 parts per million of pine oil in water. The method depends on the stable bluish-green color produced when pine oil is reacted with vanillin-hydrochloric acid reagent at 60° C. for 25 minutes. Interferences, where present, are removed with ion exchange resins.

Continued studies of acid mine wastes have shown quantitatively that oxygen, water vapor, or water alone, will not form sulfuric acid or dissolve iron from pyrite. When pyrite was exposed to oxygen saturated with water vapor, a large amount of sulfuric acid and dissolved iron was formed. When pyrite was kept immersed in water saturated with oxygen, only a small amount of sulfuric acid and dissolved iron was formed. It was brought out in a discussion[97] of a magazine article that coating an acid-producing surface to seal it from contact with air to stop acid formation is impractical, both because of the nature of the surface, and because interference with the movement of seepage water would quickly break surface seals.

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[95] Martinez, B P., Regeneration of Spent Pickle Liquors: Bureau of Mines Inf. Circ. 7672, 1953, 18 pp.

[96] Sutton, J. A., A Colorimetric Method for Determining Pine Oil in Water: Bureau of Mines Rept. of Investigations 4990, 1953, 15 pp.

Recommendations were made to a number of plants on methods of reclaiming waste materials and to abate stream pollution caused by the discharge of such materials to streams.

As a part of the New England-New York Inter-Agency Survey of Water-Borne Mineral Wastes, inspections were made by chemical engineers of 575 industrial plants. These inspections resulted in surveys of 397 plants discharging consequential flows of water-borne wastes of mineral origin to the streams of New York and the New England States. Unique waste-treatment and disposal methods were devised, and conservation steps were explained and encouraged, where practical.

SURVEY AND STUDY OF CARBONIZING BEHAVIOR OF COALS AND BLENDS

Survey of Carbonizing Properties of American Coals

The survey of the carbonizing properties of coals of the United States was continued at an accelerated rate, made possible by discontinuing tests of blends and tests at temperatures other than 900° C. Carbonization tests by the BM-AGA method, which has been improved during its 25-year application, were made on representative samples from important beds of the Appalachian region. The suitability of coals for making metallurgical coke was stressed in all tests, although the yields and quality of the carbonization products were determined. Expansion tests in the sole-heated oven were made on most samples containing 65 percent or more fixed carbon on the dry, mineral-matter-free basis.

During the reporting period, coals have been tested on a county basis to coordinate the coal sampling for carbonization with that of the survey of the preparation characteristics of coals, as part of the investigations of known recoverable reserves and properties of coking coals. Samples were taken in Armstrong, Cambria, Centre, Clarion, Clearfield, Elk, Huntingdon, Indiana, and Washington Counties in Pennsylvania; Harrison, Logan, Monongalia, McDowell, Raleigh, and Wyoming Counties in West Virginia; Letcher, Leslie, Pike, and Hopkins Counties in Kentucky; and Anderson, Campbell, Overton, Putnam, Sequatchie, and Marion Counties in Tennessee. Seventy-eight single coal samples from these four States were tested. In addition to these, 3 Virginia coals, 1 Wyoming coal, and 20 blends were tested. Since data on the carbonizing properties and yields of carbonization products is expected to be published later, only the following brief discussion, by States and counties, is included in this report.

Pennsylvania Coals

Armstrong County. - Seven coals, representing the two important beds in Armstrong County, ranked as high-volatile A bituminous, but none was high in that classification. Two samples from the Upper Freeport bed had satisfactory cokemaking and expanding properties, although their sulfur contents were rather high, whereas two other samples from the same bed coked less strongly. However, both probably could be used in coking blends, and their blending with expanding coals should present no problem for both contracted significantly. Lower Kittanning coals yielded coke of rather low tumbler stability, and both contracted more than 30 percent.

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[97] Berk, A. A., Discussion on "Formation of Acid-Mine Drainage," by K. L. Campbell and Arthur Colmer: Min. Eng., vol. 4, No. 11, November 1952, pp. 1077-1078.

Cambria County. - Lower Kittanning coal from this county ranked high in the medium-volatile group and expanded. Its blends with 80, 60, 40, and 20 percent high-volatile A Pittsburgh-bed coal coked strongly. Maximum coke strength obtainable from a binary blend of these coals was attained when they were blended in approximately equal proportions, but the commercial carbonization of equiweight binary blends containing a strongly expanding coal generally is impractical, because they are prone to develop excessively high wall pressure.

Centre County. - Coals from the Upper Kittanning and Brookville beds were medium volatile in rank and were high in ash and sulfur. Except for the relatively low hardness factor of Brookville coke, the strength indexes of both cokes were satisfactory. Brookville contracted, whereas most coals of similar rank expand; this unusual property is attributed, at least partly, to the high percentage (14.5) of ash in this coal sample.

Clarion County. One sample each of Upper Freeport and Lower Kittanning coals coked less strongly than the average high-volatile coal carbonized in commercial blends. Both contracted moderately and were rather high in sulfur. Another sample of Lower Kittanning coal from this same county contracted more than the first and yielded weaker coke.

Clearfield County. - Medium-volatile Lower Freeport coal coked strongly enough to qualify as a coal suitable for blending with low-sulfur contracting coals. The top and bottom benches of medium-volatile Lower Kittanning coal, sampled from the same mine, differed significantly both in chemical composition and coking properties. The top bench was moderate in ash content and expanded strongly, whereas the bottom bench, which was excessively high in ash and sulfur, contracted slightly and yielded coke of lower tumbler stability. A blend containing equal parts of these two coals yielded coke similar to that made from the top-bench coal. Another Lower Kittanning coal from this county, which ranked as high-volatile A and was highly contracting, coked normally for its rank.

Elk County. - Middle Kittanning high-volatile A bituminous coal contracted substantially, and its coke was high in sulfur and of rather low tumbler hardness.

Huntingdon County. - A composite of raw slack and washed nut sizes from the Fulton, Barnett, and Speer beds was the only coal tested from the Broadtop Field. It ranked as low-volatile bituminous, expanded moderately, and coked very well as a blend with 80 percent Pittsburgh-bed coal.

Indiana County. - Upper Freeport and Lower Kittanning coals ranked very low in the medium-volatile classification and had expected carbonizing properties. Although both yielded fairly strong coke, their high sulfur contents and expanding properties would restrict their use in metallurgical coking blends. Another Upper Freeport coal, which ranked high in the high-volatile A group but contained 17.4 percent ash, contracted and yielded coke of low tumbler stability and hardness.

Somerset County. - Low volatile Upper Freeport and Upper Kittanning coals yielded the strong coke generally obtained from coals of their rank. As both expanded strongly, they should be carbonized commercially only as blends with coals of lower rank (that is, high volatile).

Washington County. - Pittsburgh-bed coal coked satisfactorily for its high-volatile A rank. Its blends with 20 and 30 percent Pocahontas No. 3 yielded coke of metallurgical grade.

West Virginia Coals

Harrison County. - Pittsburgh-bed coal yielded high-sulfur, weak coke, but gave exceptionally high yields of tar and light oil, at 22.0 and 4.13 gallons, respectively.

Logan County. - Alma and Lower Cedar Grove yielded coke with low tumbler indexes. Blending with 20 and 30 percent Pocahontas No. 3 strengthened the coke from both coals significantly. The cokes from Lower Cedar Grove and its blends were stronger than those from Alma coal and its blends; this difference is attributed to the lower fixed carbon content of Alma coal.

Monongalia County. - Pittsburgh-bed coal contained too much sulfur (3.2 percent) to meet present metallurgical standards, in addition to which the coke was inferior physically to those yielded by most Pittsburgh-bed coals tested previously.

McDowell County. - Ten coals from this county yielded well-fused coke. Upper, Middle, and Lower Cedar Grove coals were similar chemically,and their yields of carbonization products were normal for their high-volatile A rank. The quality of their cokes shows that they are suitable for producing metallurgical coke if blended with low- or medium-volatile coals. Their blending should cause no unusual expansion problem because all three contracted in sole-heated oven tests. The Middle bed probably would require a greater proportion of low-volatile blending coal because it coked less strongly than the Upper and Lower beds. Eagle ranking high in the high-volatile A group, qualifies as a coking coal, although its sulfur content was rather high. This coal contracted strongly for its rank. The coals from six other beds - Douglas, Bradshaw, Welch, Fire Creek, Pocahontas No. 9, and Pocahontas No. 5 - ranked as medium- or low-volatile and yielded strong cokes. As all expanded in the sole-heated oven, probably they should be blended with high-volatile coals if used to produce metallurgical coke. Three that expanded less than 3 percent can be coked singly if low charge densities are maintained.

Raleigh County. - Five coals ranked as high-volatile A and 5 as medium-volatile. Upper Hernshaw contracted excessively, and its coke had low stability in the tumbler test. Cedar Grove did not give a fused coke, probably because the bed was sampled too near the outcrop. Two samples from the No. 2 Gas bed differed chemically, and their carbonizing properties were in line with expected behavior in view of the chemical differences. Powellton ranked high in the high-volatile A group and exhibited the highly satisfactory coking properties typical of this well-known bed. The five medium-volatile coals representing the Upper Eagle, Eagle (top bench), Eagle, Eagle (lower bench), and Lower War Eagle all coked well enough to qualify as metallurgical coals, although the cokes from Eagle and Eagle (top bench) had low 1/4-inch tumbler indexes. Upper Eagle contracted highly for its medium-volatile rank, whereas Eagle (top bench) expanded to warrant its being considered as a source of difficulty if used as a major constituent of commercial coking blends.

Wyoming County. - Three high-volatile A coals yielded coke of low tumbler stability and hardness - the high ash content (16.0 percent) of Campbells Creek may account for its low coke strength. Chilton- and Eagle-bed coals coked strongly enough to qualify as metallurgical coking coals.

The carbonizing properties of two Beckley-bed coals, one from the Caretta No. 5 mine in McDowell County and one from the Glen Rogers No. 2 mine in Wyoming County, have been reported.[98] Both coals ranked as low-volatile bituminous and both were carbonized singly and as blends with 70 and 80 percent high-volatile coal from the Pittsburgh bed. Caretta No. 5 coal had less volatile matter (ranked higher) than Glen Rodgers No. 2, and in line with usual trends, the latter coal yielded less coke and more of the other carbonization products. Results of blending tests showed both coals to be suitable for blending with high-volatile A coals for the production of metallurgical coke.

Kentucky Coals

Letcher County. - Eight coals representing 7 beds contained 55.3 to 62.2 percent dry, mineral-matter-free fixed carbon. Upper Elkhorn No. 3 probably is the most strongly coking of these, although the sample tested was too high in ash (17.9 percent) to yield coke of satisfactory hardness. The coals from the other beds - Hazard No. 7, Hazard No. 4, Whitesburg, Amburgy, Upper Elkhorn No. 2, and Upper Elkhorn No. 1 - yielded coke of rather low stability and hardness. These coals could not be substituted in equal proportions for strongly coking high-volatile coals now used in blends to produce metallurgical coke.

Leslie County. - As the Upper Elkhorn No. 3 bed was sampled by core drilling, the sample was small and it was tested only in ternary blends with Hazard No. 4 from Letcher, Leslie and Perry Counties, and Pocahontas No. 3 coals. These samples of Elkhorn No. 3 and Hazard No. 4 had similar cokemaking properties; neither coked as strongly in blends as Pond Creek-bed coal from Pike County, which is a well-known high-volatile metallurgical coal.

Hopkins County. - Two high-volatile B coals from No. 9 and No. 11 beds in this county in western Kentucky, were carbonized at 600° C. to provide low-temperature tar for the Synthetic Liquid Fuels Branch at Bruceton, Pa. Coal from No. 11 bed yielded 27.2 gallons of tar per ton, which is well above the average of 21.9 gallons for high-volatile coals tested previously. The yield from No. 9 bed was slightly below average. Both coals have higher-than-average yields of tar acids; No. 11 yielded about twice the average yield.

Tennessee Coals

Generally, coals from Tennessee yield the weak fingery coke characteristic of coals ranking low in the high-volatile A group, that is, with percentage of fixed carbon substantially below the upper limit of this rank class and with fairly high percentages of volatile matter. Their yields of ammonium sulfate are appreciably higher than the average for high-volatile coals.

A report on the carbonizing properties of the two Tennessee coals, one from the Jellico bed in Campbell County and the other from the Sewanee bed in Marion County, has been published.[99] Both coals ranked as high-volatile A bituminous, but

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[98] Reynolds, D. A., Davis, J. D. Wolfson, D. E., Naugle, B. W., Brewer, R. E., Birge, G. W., and Frederic, W. H., Carbonizing Properties: West Virginia Coals From the Beckley Bed, Caretta No. 5 Mine, McDowell County, and Glen Rogers No. 2 Mine, Wyoming County: Bureau of Mines Bull. 522, 1953, 27 pp.

[99] Reynolds, D. A., Davis, J. D., Birge, G. W., Brewer, R. E., Wolfson, D. E., Ode, W. H., and Naugle, B. W., Carbonizing Properties: Tennessee Coals From the Jellico Bed in Campbell County and the Sewanee Bed in Marion County: Bureau of Mines Bull. 523, 1953, 35 pp.

Sewanee was quite close to the borderline between high-volatile A and medium-volatile and exhibited some carbonizing properties more characteristic of medium-volatile coals. Jellico coke was well fused, medium grained and extensively fissured. The physical properties of the coke were improved markedly by blending Jellico with 20 percent Pocahontas No. 3.

Sewanee coke was similar to that yielded by medium-volatile coals in that it was large size and strong. Blending with 40 percent Pocahontas No. 3 (a procedure that would not be practicable in most coke plants because both coals expand) raised the shatter indexes but did not alter other physical properties of the coke appreciably. Blending with 30 percent Pittsburgh coal lowered the average size and shatter indexes of the coke; these effects were greater when 50 and 70 percent Pittsburgh was used.

Anderson County. - Coals from this county ranked relatively low in high-volatile A classification and 6 of the 7 tested yielded coke of low stability, as measured by the 1-inch tumbler index. These 6 represented the Pee Wee, Big Mary, Windrock, and Poplar Creek beds, and their content of dry mineral-matter-free fixed carbon ranged from 58.6 to 60.1 percent. All contracted enough to permit blending with expanding coals of higher rank. Coal Creek bed coal ranked highest of the coals from Anderson County and yielded the strongest coke. Although less strongly coking than the better high-volatile coals of West Virginia, the Coal Creek coal could be blended to produce metallurgical coke.

Campbell County. - Rex-bed coal, the only coal tested from this county, was high in sulfur and yielded coke of low stability, although the coke hardness was satisfactory.

Overton County. - Two samples from the Wilder or Bon Air No. 2 bed were high in ash and sulfur. Considering the moderate contents of fixed carbon of both coals, their cokes were satisfactorily strong as judged by their shatter and 1-inch tumbler indexes. However, their hardness factors, or 1/4-inch tumbler indexes, were rather low, although these probably would be improved were the coals cleaned to a lower ash content. As both contained more than 3 percent sulfur, they are not classed as metallurgical coals by present standards.

Putnam County. - Wilder, or as it is known locally, the Bon Air No. 2-bed coal contained excessively high proportions of ash and sulfur. Its coke was considered weak, chiefly because of its low hardness factor.

Sequatchie County. - Sewanee-bed coal ranked high in the high-volatile A classification and yielded the strong coke characteristic of that coal rank. Although not low in ash and sulfur, the chemical composition of this coal would not preclude its use for producing metallurgical coke.

Virginia Coals

Buchanan County. - Jewell and Douglas A bed coked strongly. Their chemical composition and expanding properties, and the quality of their cokes show both to be suitable for metallurgical use.

Tazewell County. - Jewell coal from this county ranked as medium-volatile bituminous and was exceptionally low in ash and sulfur. As this coal expanded moderately in the sole-heated oven and yielded very strong coke, it could be used to produce metallurgical coke in appropriate blends.

Wyoming Coals

Lincoln County. - Subbituminous B coal from the Adaville bed yielded nonagglomerated char at 900° C. Free-swelling and agglutinating tests of this coal also proved it to be noncoking. This coal could be carbonized satisfactorily in continuous processes for producing char suitable for chemical use.

Coal Expansion During Carbonization

Low-volatile coals are not coked singly in modern ovens because of their expanding properties, but since they have the ability to increase both the strength and yield of coke obtainable from nonexpanding coals of high-volatile rank, they are used widely in blends to produce metallurgical coke. The proportion of low-volatile coal in coking blends usually is 10 to 25 percent for furnace coke and 20 to 25 percent for foundry coke. Because of this, low-volatile coals are carbonized only as minor constituents of blends. Previous investigations have shown that the physical properties of coke made from 100 percent coal of this rank are not closely related to those of coke made from its blends with large proportions of high-volatile coal, therefore BM-AGA tests of straight low-volatile coal are no longer being made. However, as the expanding property of low-volatile coals often is imparted in part to their blends, coke oven operators are particularly interested in their expanding properties for they determine to a large extent their suitability for blending. In the coking coal investigations therefore, the expanding properties of low- and medium-volatile coals are determined in the sole-heated oven. Experimental results are reported as percentage expansion, or contraction, at a bulk density of 55.0 pounds per cubic foot, 1 percent moisture, and 0-3 percent plus-4-mesh coal. As these data are expected to be published later, only a brief review of the work is given below.

Expansion of Low-Volatile Coals

As reserves of some of the low-volatile coking coals used in metallurgical coking blends are becoming depleted, the Bureau of Mines is endeavoring to evaluate the carbonizing properties of coals of similar rank from other beds to facilitate the selection of replacement coals. Eleven low-volatile coals from McDowell, Raleigh, and Wyoming Counties in southern West Virginia were tested in the sole-heated oven. As their expansions ranged from zero to 25.2 percent, as compared to 17 to 22 percent for the well known Pocahontas No. 3 from the same coal field, most of these coals could be substituted for Pocahontas No. 3 insofar as expansion is concerned, provided that the proportions blended were adjusted suitably.

Expansion tests on Pennsylvania low-volatile coals from the Upper and Lower Kittanning beds showed that these coals expand excessively. This had caused a large steel company difficulty in operating their coke plant when carbonizing these coals as blends with higher-volatile (lower ranking) coals. Lower Kittanning expanded more than any coal tested previously.

Effect of Coal Cleaning on Expansion

Bureau investigations have shown the expansion of coal generally increases (or contraction decreases) when they are tested by carbon tetrachloride float-and-sink methods or cleaned by table processes. This effect is believed to be due chiefly to the removal of ash and sulfur. A mixture of Upper and Lower Freeport slack coal was changed from 13.6 percent contracting to 13.1 percent expanding by washing in a commercial cleaning process that lowered its ash content from 12.9 to 6.6 percent. The

3/4- by 1/4-inch size of this same blend expanded 9.8 percent after cleaning by the Chance-Cone process.

Effect of Blending on Expansion

The effect on expansion of varying the ratio in which high-volatile A Alma-bed coal was blended with low-volatile Pocahontas No. 3 and medium-volatile Freeport coals is shown graphically in figure 19. The upper curve, which is rather typical for blends of coals of these ranks, shows that the contraction of Alma coal decreased significantly on blending with less than 20 percent low-volatile coal and that the expansion of the blends increased at a nearly constant rate as the proportion of low-volatile coal was increased beyond 28 percent. However, although this general type of behavior is true for most low-volatile coals, the Freeport coal behaves quite differently, as shown by the lower curve for the Alma-Freeport blends. The behavior of this Freeport coal in blends differed markedly from that of Pocahontas No. 3, although they expanded about the same when tested singly. Up to 40 percent of the Freeport had relatively little effect on the contraction of Alma, whereas this percentage of Pocahontas No. 3 changed Alma from 11.6 percent contracting to 4 percent expanding.

Analysis of Carbonization Data and Study of Precision of Coke Tests

A review and analysis of data obtained from all tests in the BM-AGA apparatus is being made to determine correlations as between chemical and physical properties of coals and the yields, composition, and physical characteristics of their carbonization products. The data and correlations from this study were, in part, responsible for recent changes in the BM-AGA test procedure, whereby tests are now made only on single high-volatile coals at a single temperature. From the single test and the correlations developed, the coking industry and coal operators are furnished adequate information on the behavior of coals of previously unknown coke-making ability, and the overall testing time is materially reduced so more coals can be tested.

Considerable progress was made in evaluating the methods used for determining the physical properties of metallurgical cokes. Reports dealing with the precision of the shatter test1/ and screen analysis2/ tests were completed. Information contained in these reports makes it possible to state whether differences in the physical properties determined for different lots of metallurgical cokes can logically be attributed to experimental variations, or must be accounted for on the basis of variations in operating conditions and/or coals used. Information as to the limiting or theoretical precision for the shatter test and screen-analysis results also is included in these reports. By comparing the theoretical values with those determined for commercial and experimental cokes, it should be possible to obtain relative numerical estimates of uniformity (or nonuniformity) of commercial and experimental cokes as measured by the different physical test indexes.

This approach is being used to study cokes made in the Bureau of Mines experimental coke oven3/ at the Southern Experiment Station, Tuscaloosa, Ala. This oven,

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1/ Gayle, J. B., and Auvil, H. S., A Study of the Precision of the Shatter Test on Coke: Bureau of Mines Rept. of Investigations 4987, 1953, 13 pp.

2/ Gayle, J. B., Theoretical Precision of Screen-Analysis Results: Bureau of Mines Rept. of Investigations 4933, 1952, 9 pp.

3/ Gayle, J. B., and Auvil, H. S., Development of New, Experimental Coke Oven: Bureau of Mines Rept. of Investigations 4923, 1952, 17 pp.; New Test Coke Oven: Chem. Eng., vol. 60, No. 11, 1953, pp. 142 and 144.

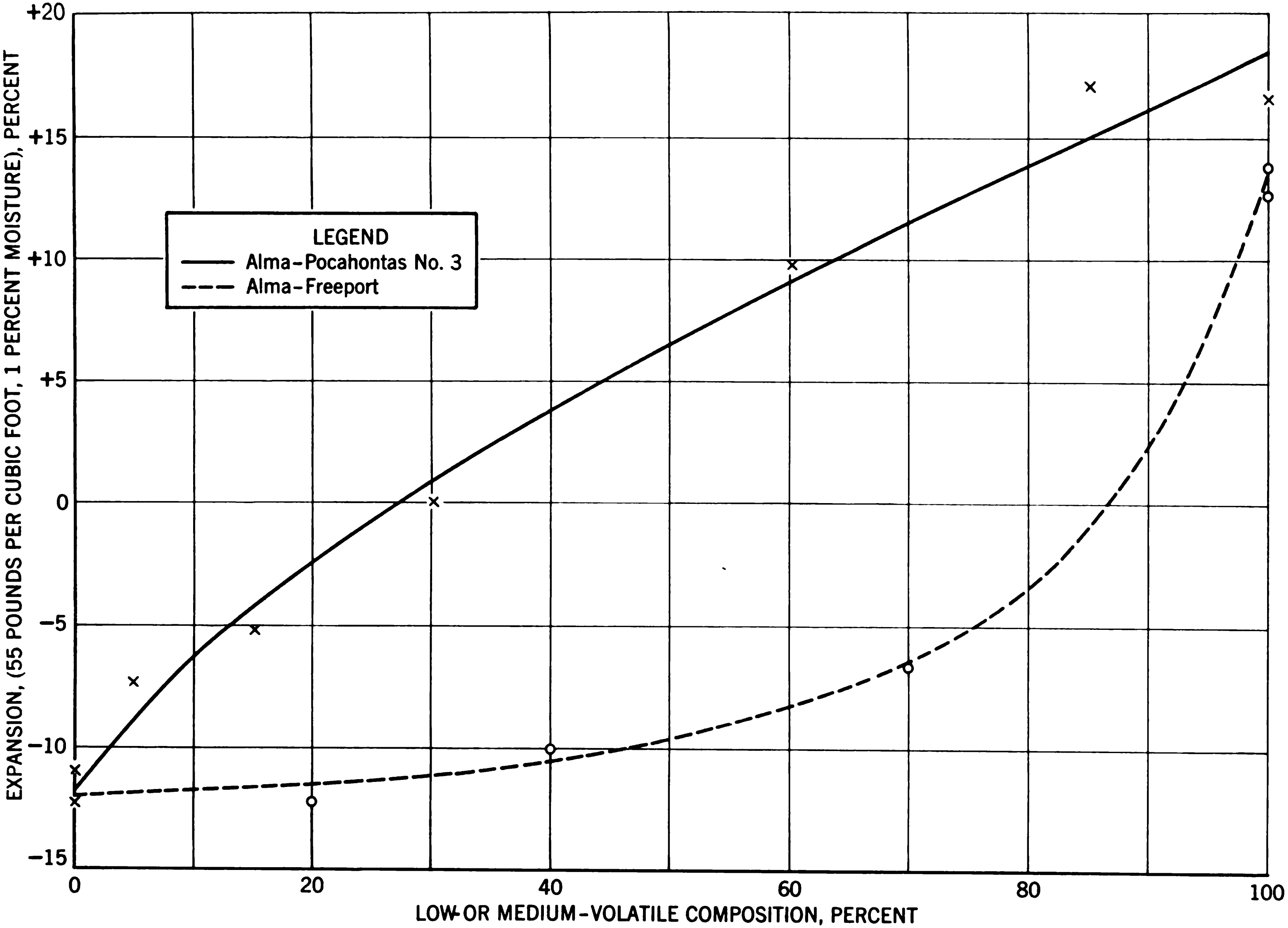

Figure 19. - Expansion of coal blend.

designated as the Tuscaloosa oven, has been operated intermittently for several years. It has performed satisfactorily during preliminary investigations of the effects of operating variables on the quality of coke produced and determination of the amount of pressure developed during the carbonizing process.

Study of the Mechanism and Kinetics of Carbonization

To evaluate critically the present state of knowledge regarding the mechanism of coking, a survey and evaluation of past research work on carbonization was made.[4/] It was shown that bituminous coals consist of complex aggregations of organic compounds and/or polymers whose molecular weight and structures vary widely when such materials are heated. Then the more fusible components soften, the more volatile vaporize, and the thermally less stable decompose. Furthermore, the available experimental data on the thermal decomposition of coal fit the concept that coal carbonization, with consequent coke formation, is the result of the competing and simultaneous processes of fusion - without simultaneous depolymerization -, solvent extraction, vaporization, decomposition, and polymerization. The interaction of these processes and their kinetic relationships for different time-temperature histories govern the yield and quality of the products. For a coal and/or other material to give a well fused, coherent residue an appreciable fraction of the material must fuse at an elevated temperature; simultaneous decomposition and polymerization must occur at or near the fusion temperature; and the vapor pressure of the fluid material must be quite low.

Entrained and Fluidized Low-Temperature Carbonization

The Bureau cooperated with the Texas Power & Light Co., Aluminum Company of America, and several engineering contractors, as mentioned in the section on drying low-rank coals, in designing a prototype carbonizer based on the process as developed at the Bureau's Denver laboratories. Figure 20 shows a schematic diagram of the 25-ton-per-day pilot plant, and figure 21 a photograph of the pilot-scale equipment used in this development work at Denver. The commercial carbonizer at Rockdale, Tex., capable of handling 750 tons of dried coal per day, was under construction in November 1953 and scheduled for completion and testing in March 1954. If this operation is successful, additional carbonizers at this plant will be constructed as needed.

In the pilot-scale carbonizer at Denver, the particles of dried coal were heated in suspension in a vertical-moving gas stream to about 900° F. About half of the heat required to carbonize the coal was supplied by combustion of fine char particles in the bed with the air used to transport the coal to the carbonizer. The remainder was supplied by heat transferred through the walls of the alloy retort tube. The carbonizing temperature and the velocity of the gas through the retort were selected to produce the maximum yield of tar from the dried coal. Throughout the range of coals studied at Denver it was found that the optimum carbonizing temperature was about 900° F. and the optimum residence time of the particles 10 to 15 minutes. The mixture of char, gas, tar vapor, light-oil vapor, and water vapor leaving the carbonizer was passed through heated cyclones and an electrostatic precipitator for recovery of the char, and then it went through a condensing system for the recovery of tar, light oil, and liquor. Experience with several coals carbonized under these conditions indicated that any noncoking coal can be carbonized using the above techniques.

[4/] Smith, F. W., and Brown, R. L., How Does Coal Coke?: Proc. Am. Gas Assoc., 1952, pp. 719-729.

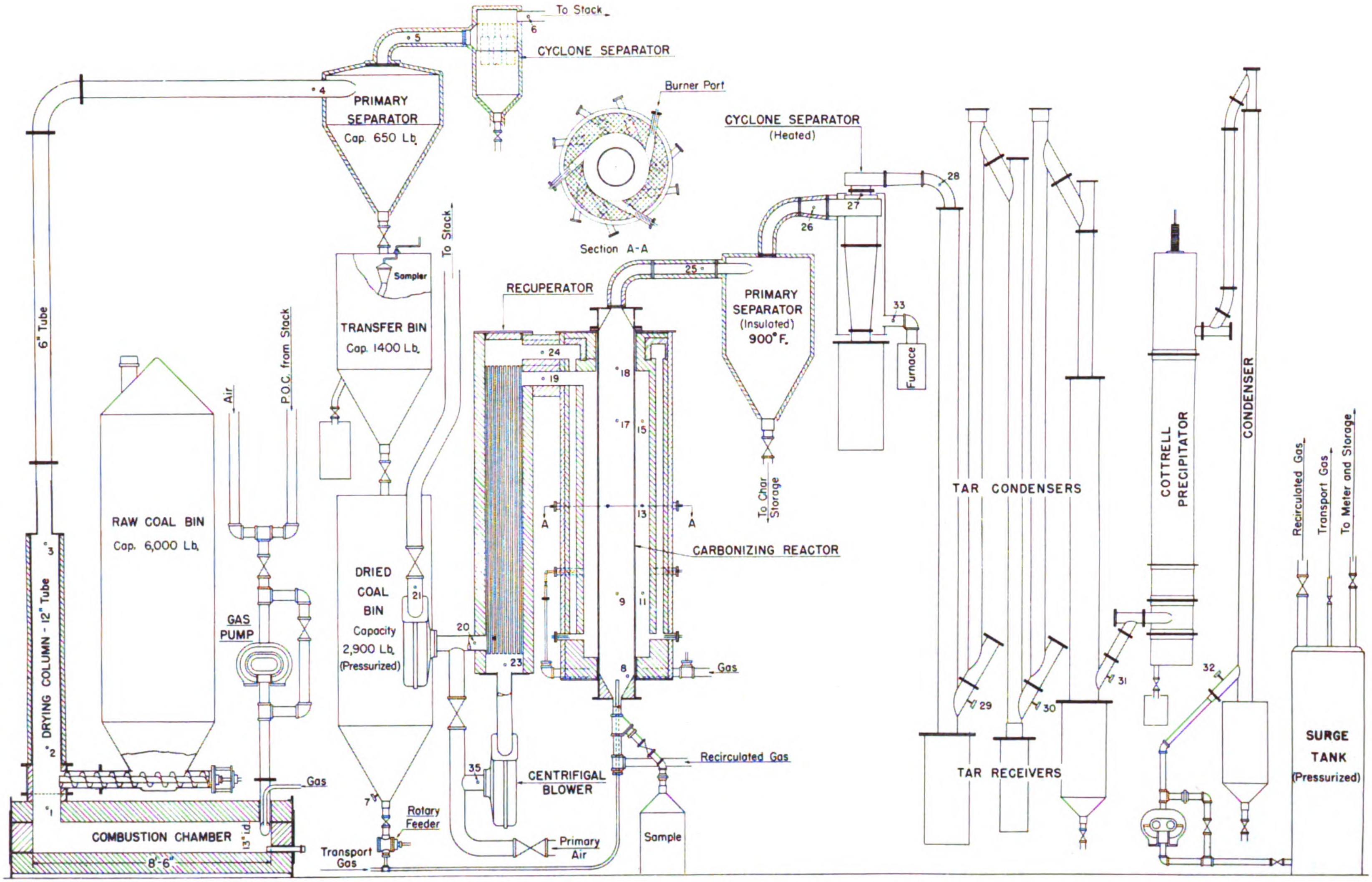

Figure 20. - Pilot plant for drying and carbonizing fine coal—capacity 25 tons per day.

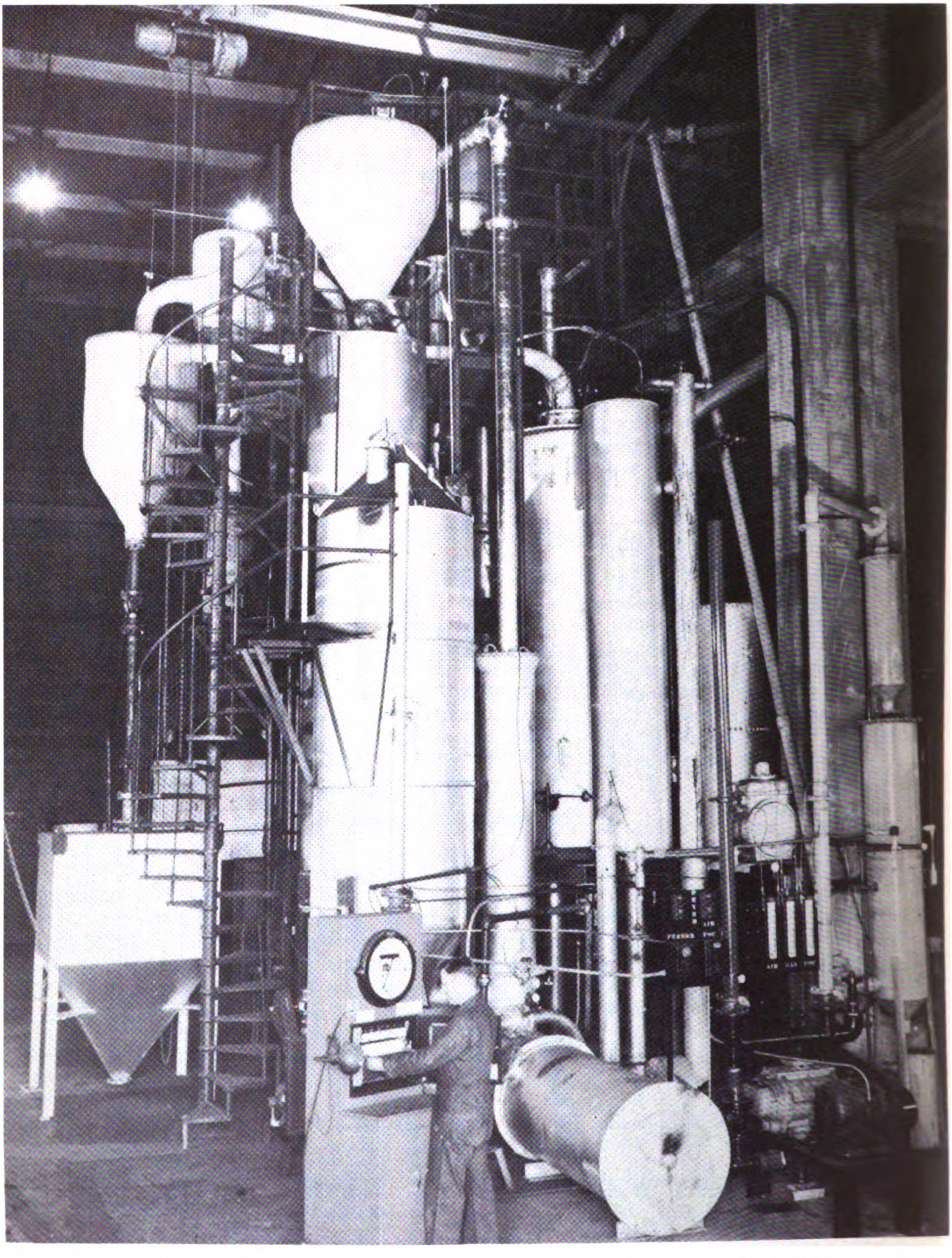

Figure 21. - Integrated drying and carbonizing plant, Denver, Colo.—capacity 25 tons per day.

The following general conclusions were reached:[5]

1. Any coal containing over 12 percent oxygen on the moisture- and ash-free basis can be carbonized successfully in the entrained and fluidized state. Coals containing less than 12 percent oxygen may agglomerate and deposit coke, preventing flow of materials through the systems.

2. The yields of tar from a given coal may equal or slightly exceed the yield determined by the laboratory assay at 500° C. (932° F.).

3. The optimum temperature for maximum tar yields is about 900° F. The tars produced are primary products characterized by high tar-acid content, including a large fraction of high boiling groups.

4. The char produced contains approximately 73 percent of the potential heat in the original coal and the tar will contain 13 to 25 percent of the potential heat in the coal, depending on the volatile content of the coal.

The complete economics of low-temperature carbonization are yet to be determined on a large scale. The operation of the prototype carbonizer will provide large quantities of tar to establish its value through commercial investigations.

GASIFICATION OF COAL AND LIGNITE

Anthracite for Making Producer Gas

An investigation of the use of anthracite producer gas as fuel for process-heating applications was initiated to develop technical and economic data on various phases of gas manufacture and benefits such as improved products and better yields to be derived from faster and more uniform heating. A study of one gas-fired periodic brick-kiln plant has been made, but, since the investigation is still in progress, data from this preliminary study have not been published but are expected to be made available when the studies are completed.

Field tests to establish the technical and economic feasibility of underfiring colliery boilers with producer gas made from anthracite bone coal have been completed to determine whether high-carbon colliery refuse might prove to be a cheap source of carbon for gas production. Large quantities of suitable bone coal are available in aboveground refuse piles, and the annual production of bone is a substantial proportion of the tonnage of anthracite processed for marketing. Furthermore, since high-carbon refuse sometimes burns in refuse-pile fires that add to the problem of air pollution in the population centers of the Pennsylvania anthracite region, additional benefits might accrue also from the practical conversion of bone coal to a noncombustible state before disposal.

Though the details of this study have not been and are not expected to be published elsewhere, the conclusions resulting from this investigation are:

(1) The dry ash-removal, fixed-bed commercial producer used in the test is not practical in its present design for gasifying anthracite bone coal of 35 to 50 percent ash content. Modification should include: Provision for a deeper fuel bed to minimize troublesome channeling; grates capable of ejecting ashes at rates and in

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[5] See reference 75.

patterns necessary to maintain an effective fuel bed for gasification; larger fuel-storage hopper to reduce frequency of opening coal valves; and larger ash-storage hopper or continuous removal of ashes from hopper.

(2) The economic feasibility of converting bone coal to gas for underfiring colliery boilers is doubtful unless a gas producer of very high capacity is used so as to reduce plant investment and operating labor costs. The cost of a gas-producer plant of the type and assumed capacity (about 5,000 pounds low-grade fuel per hour per producer) would be 2-1/2 to 3-1/2 times the cost of brand new stokers for underfiring the same boilers.

(3) On the basis of overall efficiencies under comparable conditions, annual fuel costs alone per 1,000 pounds of steam for stoker firing and bone-coal producer-gas firing of colliery boilers generating 90,000 pounds per hour of steam (1,061 B.t.u. per pound) show scarcely enough difference to warrant adoption of the gas-firing practice. For example, calculations show that bone coal of 7,500 B.t.u. per pound would have to be delivered at the producer plant for not more than $1.35 per ton, if cost for fuel alone on an annual basis, at 48 percent overall efficiency, were to be held at 20 cents per 1,000 pounds of steam. At 64 percent efficiency, the same grade of fuel could rise to $1.80 delivered cost and still maintain the 20-cent annual fuel cost. However, to achieve an overall efficiency of 64 percent in the gas-firing operation requires that the gas producer and boiler each must operate, for example, at an average efficiency of 80 percent.

Gasification of Pulverized Coal With Oxygen and Steam

The intensive research and development work on the gasification of pulverized coal with steam and oxygen during the past few years has led to considerable interest in the thermodynamics of such systems, a knowledge of which is needed in: (1) Comparing theoretical calculations with experimental results; (2) predicting reactor performance from known values of the feed rates and enthalpies of coal, oxygen, and steam; (3) evaluating the effect of a known change in one variable upon the other process variables; and (4) determining the process requirements and yields at given operating conditions. Since repeated calculation of heat and material balances is tedious and time-consuming, it is readily apparent that a graphical or other simple method of solving thermodynamic problems would be very useful. Accordingly, thermodynamic charts were constructed and published in a recent paper.[6] These charts are applicable to any coal for a wide range of operating variables and may be used for pressures as high as 30 atm. Figure 22 illustrates a typical chart for a particular coal and shows how the heat loss from a reactor may be obtained for any set of operating conditions.

Gasification of Rhode Island Meta-Anthracite for Production of Mineral Wool

Since the discovery of deposits of meta-anthracite in Rhode Island in 1760, there have been many attempts to utilize this material economically, but adverse mining conditions, the high ash content (generally between 35 and 45 percent), and the low reactivity limited the uses of this meta-anthracite as a fuel. In an effort to find some use for this material, the technical feasibility of the manufacture of mineral wool from meta-anthracite by charging the fuel to a continuous slagging gas

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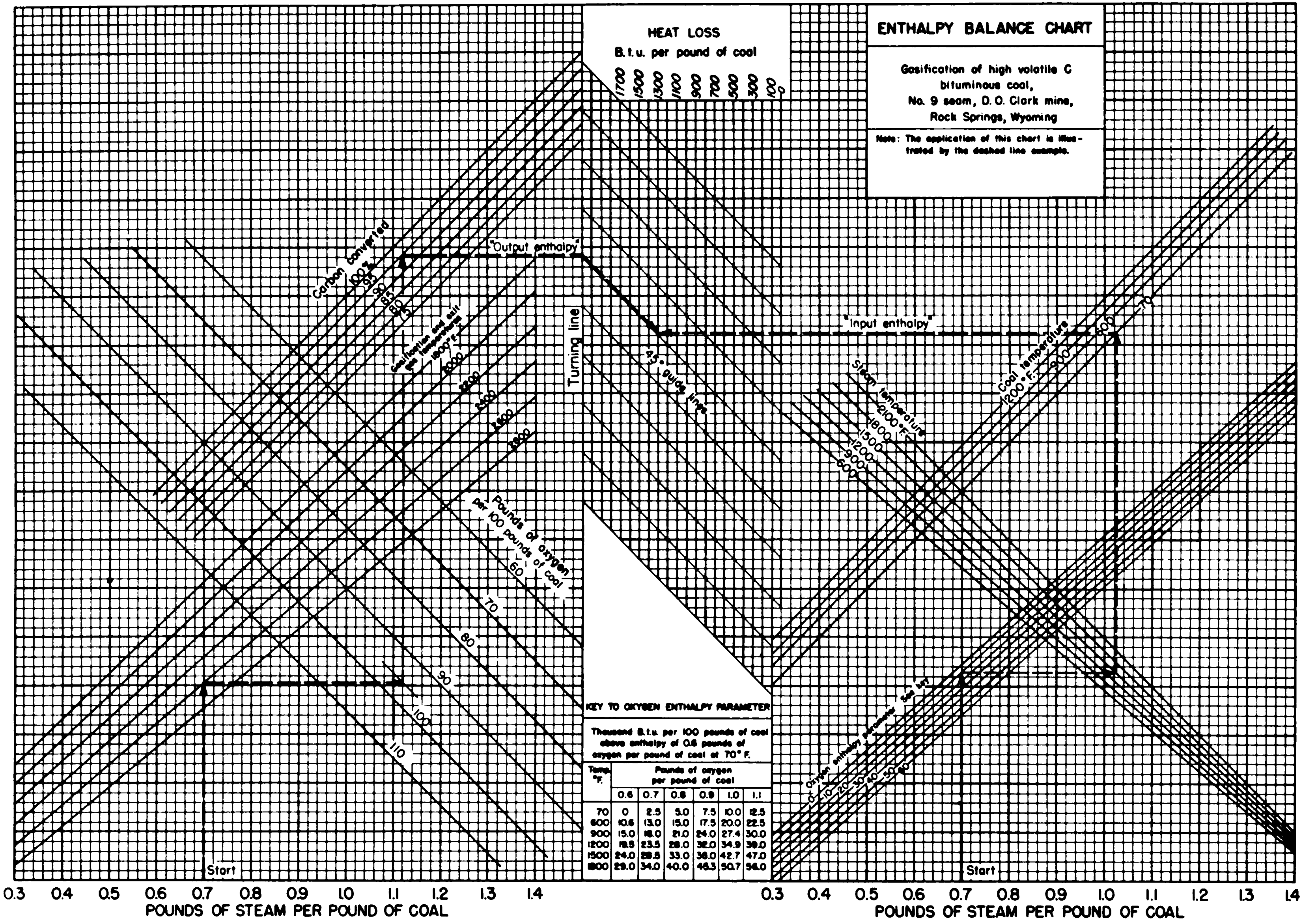
[6] Edmister, W. C., Perry, H., Corey, R. C., and Elliott, M. A., Thermodynamics of Gasification of Coal With Oxygen and Steam: Trans. ASME, vol. 74, No. 5, July 1952, pp. 621-636.



ENTHALPY BALANCE CHART

Gasification of high volatile C
bituminous coal,
No. 9 seam, D. O. Clark mine,
Rock Springs, Wyoming

Note: The application of this chart is illustrated by the dashed line example.

KEY TO OXYGEN ENTHALPY PARAMETER

Thousand B.t.u. per 100 pounds of coal above enthalpy of 0.6 pounds of oxygen per pound of coal at 70° F.

Temp. °F.	Pounds of oxygen per pound of coal					
	0.6	0.7	0.8	0.9	1.0	1.1
70	0	2.5	5.0	7.5	10.0	12.5
600	10.6	13.0	15.0	17.5	20.0	22.5
900	15.0	18.0	21.0	24.0	27.4	30.0
1200	18.5	23.5	28.0	32.0	34.9	39.0
1500	24.0	28.5	33.0	38.0	42.7	47.0
1800	29.0	34.0	40.0	45.3	50.7	56.0

Figure 22. - Enthalpy balance chart.

producer and blowing the slag stream to make wool was investigated in cooperation with the University of Rhode Island.[7]

A photograph of the slagging producer used in the investigation is shown in figure 23. From the results of several tests it was concluded that:

1. Satisfactory mineral-wool insulation can be made from Rhode Island meta-anthracite and limestone, using a slagging producer.

2. Producer gas is obtained in sufficient quantity as a byproduct in the process to more than provide all the heat requirements for making the wool.

3. A commercial plant, based upon the process and upon the design data worked out, is technically feasible.

4. A logical adjunct to the plant would be a lime kiln fired with the excess producer gas.

Gasification of Lignite

Operating results from the lignite-gasification pilot plant at Grand Forks, N. Dak., were reported in two publications.[8][9] Results are reported for 9 gasification runs covering 3,911 hours of operation during which 35.5 million cubic feet of gas was produced by partly gasifying 768 tons of natural and steam-dried lignite in the externally heated small,commercial-scale annular metal retort gasifier. The flow diagram of the plant is shown in figure 24. Lignite from the feeder enters in small increments and slowly descends into the externally heated annulus, and steam, superheated by waste flue gases, joins the lignite as it enters the annulus from the charging dome. Heat transferred through the outer wall of the annulus first dries the lignite, then carbonizes it, with formation of gas and tar, and as downward flow continues, the temperature increases and reactions between gas, tar, steam, and lignite char from gas. Principal constituents of this gas are hydrogen, carbon monoxide and carbon dioxide. About two-thirds of the length down the annulus (or at the bottom of the annulus, depending on the design), gas and unreacted steam flow through the gas offtake in the inner wall and upward in the center of the retort. When the first, or divided-annulus design is used, the residue of partly gasified lignite continues down through the lower annular reaction zone, where further gasification takes place by reaction with steam fed to the bottom of the retort. In both designs char, the residue of ungasified lignite, is extracted continuously at the bottom of the unit. Hot gas leaves the top of the gas generator and flows to the condenser and scrubbers. Part of the clean, cool gas is pumped to burners to supply heat to carry out the endothermic water-gas reaction.

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[7] Crawford,T.S.,Corey, R. C., Schwartz, C. H., Spano, L. A., and Carpenter, E. L.: A Slagging Gas Producer for the Production of Mineral Wool From Rhode Island Meta-Anthracite: University of Rhode Island Engineering Experiment Station, Bull. 3, July 1953, 35 pp.

[8] Burr, A. C., Holtz, J. C., Koth, A. W., and Oppelt, W. H., Gasification of Lignite in a Commercial-Scale Pilot Plant, Progress Report for 1947-48: Bureau of Mines Rept. of Investigations 4940, 1953, 28 pp.

[9] Burr, A. C., Ellman, R. C., Hoeppner, J. J., Holtz, J. C., Kamps, T. W., Kube, W. R., Ongstad, O. C., and Oppelt, W. H., Gasification of Lignite in a Commercial-Scale Pilot Plant, Progress Report January 1, 1949, to June 30, 1950: Bureau of Mines Rept. of Investigations 4997, 1953, 48 pp.

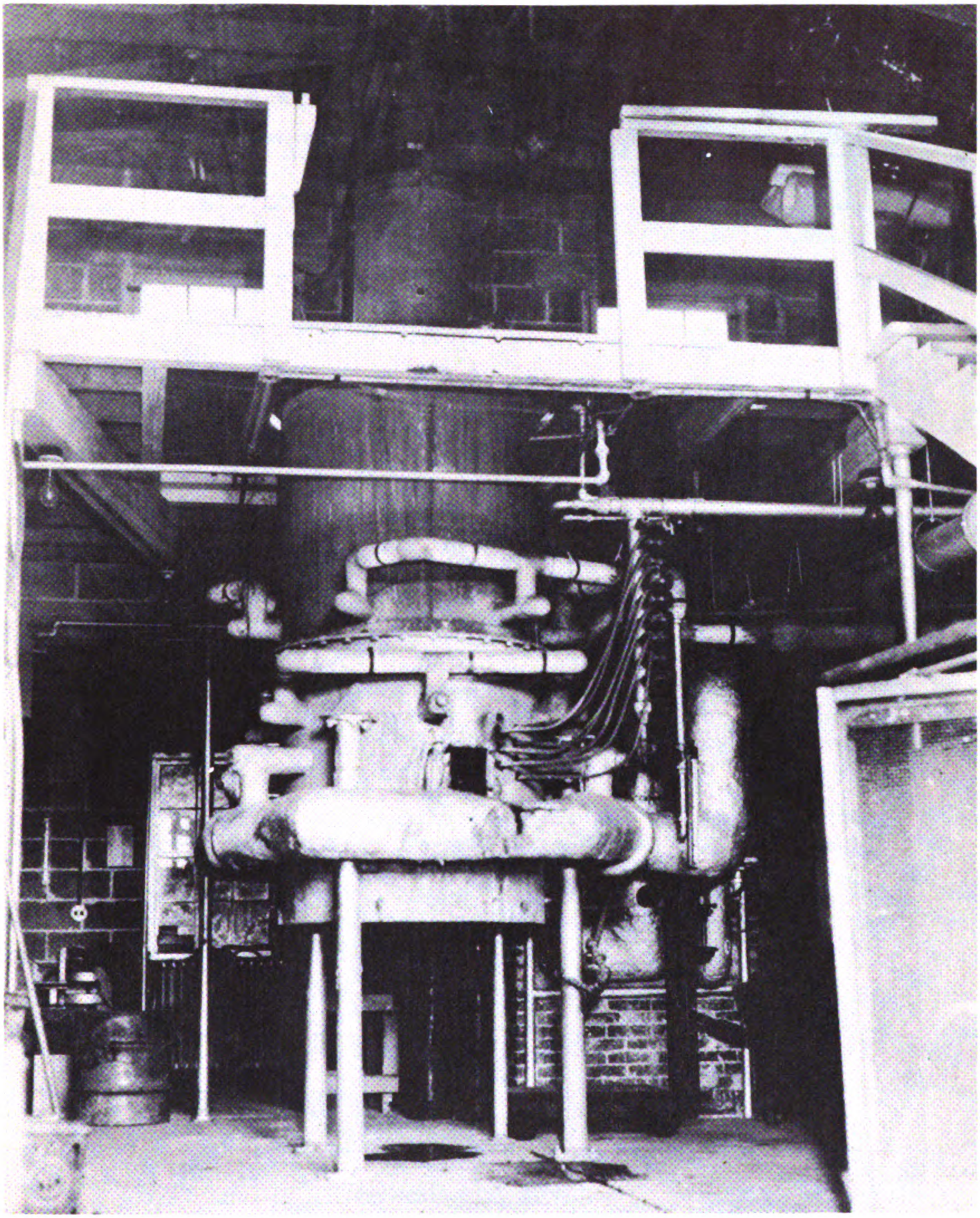

Figure 23. - Slagging producer.

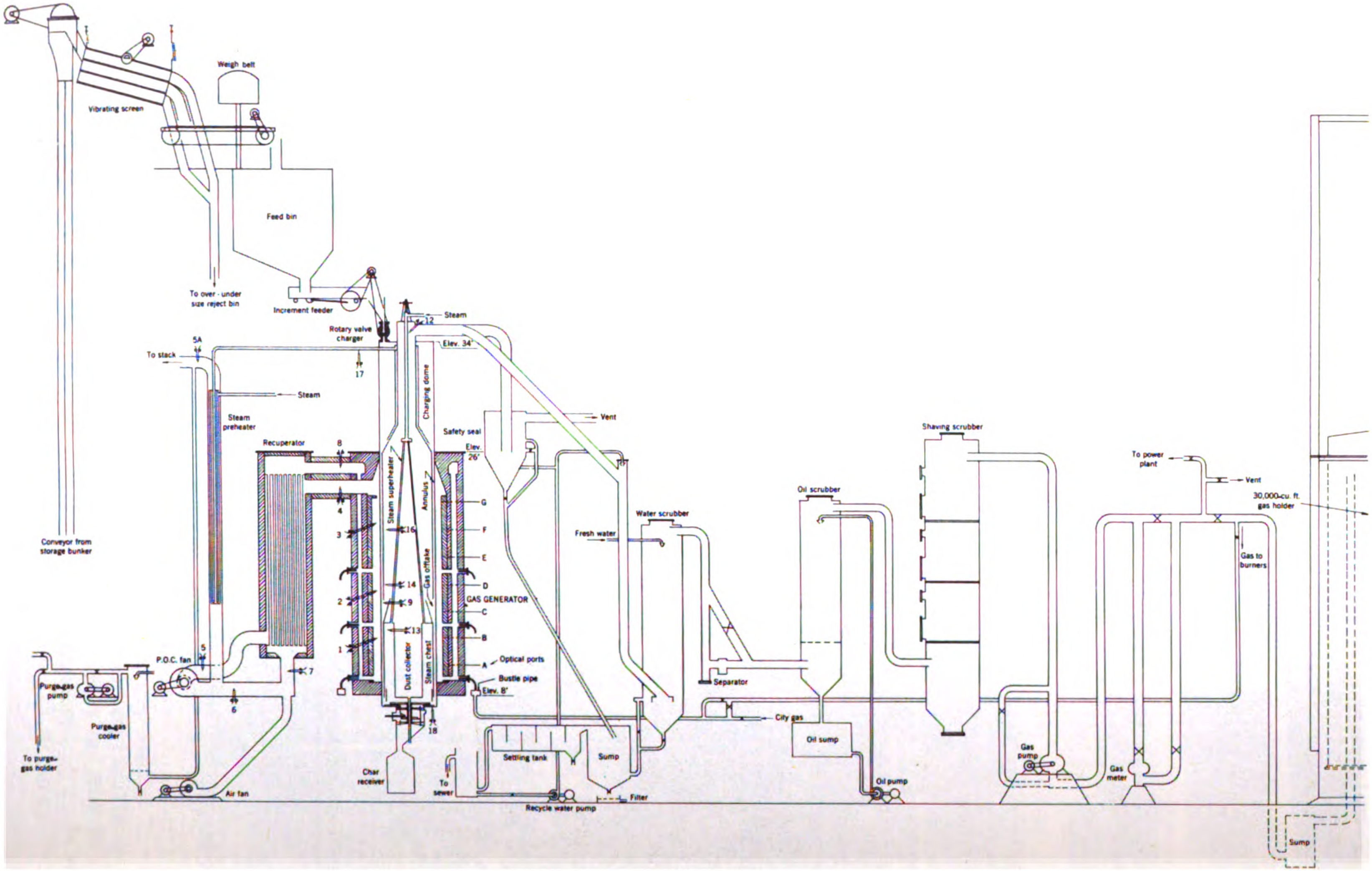

Figure 24. - Flow diagram of externally heated annular retort process for gasifying lignite, Bureau of Mines, Grand Forks, N. Dak.

Original from THE OHIO STATE UNIVERSITY

Results of the tests show that composition and volume of gas produced, and the percentage of gasification of the lignite, were controlled by lignite feed rate, steam-flow rate, and temperature in the furnace. Ratio of hydrogen-carbon monoxide in the product gas was varied over a wide range. Typical results are shown in table 1.

TABLE 1. - Range of H_2/CO ratio of product gas obtained under various operating conditions

H_2/CO ratio	[1]1.85	2.49	4.63	6.34	8.99
Process steam admitted, percent of lignite feed	51.4	21.1	108.1	158.4	266.6
Gas composition, percent:					
CO_2	10.5	15.9	22.4	25.1	27.2
Illuminants	0.1	0.2	0.2	0.4	0.2
CO	29.9	22.6	13.1	9.7	6.9
H_2	55.4	56.2	60.7	61.4	62.3
CH_4	3.5	4.3	2.6	2.7	2.6
C_2H_6	0.1	0.3	0.5	0.2	0.3
N_2	0.5	0.5	0.5	0.5	0.5
Heating value B.t.u./cu.ft.	310	303	274	266	256
Gas per pound of carbon gasified...cu. ft.	78.2	75.1	82.5	83.8	85.8
($CO+H_2$) per pound of carbon gasified cu. ft.	66.7	59.2	60.9	59.6	59.4

[1] Steam-dried lignite used as feed; all other tests made with natural lignite.

The amount of process steam required increased rapidly with increasing H_2-CO ratio. High hydrogen-carbon monoxide ratios were obtained by reducing the carbon monoxide concentration of the product gas, with relatively little change in actual hydrogen percentage in the gas.

Gas yield per ton of m.a.f. lignite was directly related to percentage of carbon gasified, and the rate of producing gas was directly related to lignite feed rate, since percent carbon gasified varied only over a relatively narrow range. At fixed lignite feed rate and furnace temperatures, percent carbon gasified increased slowly with increase in steam rate, and added steam serving principally to alter gas composition by water-gas shift. Typical results are presented in table 2.

TABLE 2. - Gas yield as function of percent carbon gasified

Percent carbon gasified	Gas yield per ton m.a.f. lignite, M cu. ft. (SGC)[1]
59.4	62.7
68.0	82.6
69.1	83.1
73.9	87.2
74.3	89.6

[1] Standard Gas Condition, that is, 60° F., 30 inches Hg, saturated with water vapor.

Gas-production rates for this system ranged from 6 to 16.4 cu. ft. per hour. The highest production rate and the lowest hydrogen-carbon monoxide ratio were obtained by gasifying steam-dried lignite. Typical heat balances for a series of hydrogen-carbon monoxide ratios from 1.8 to 4.0 are shown in figure 25. Potential heat

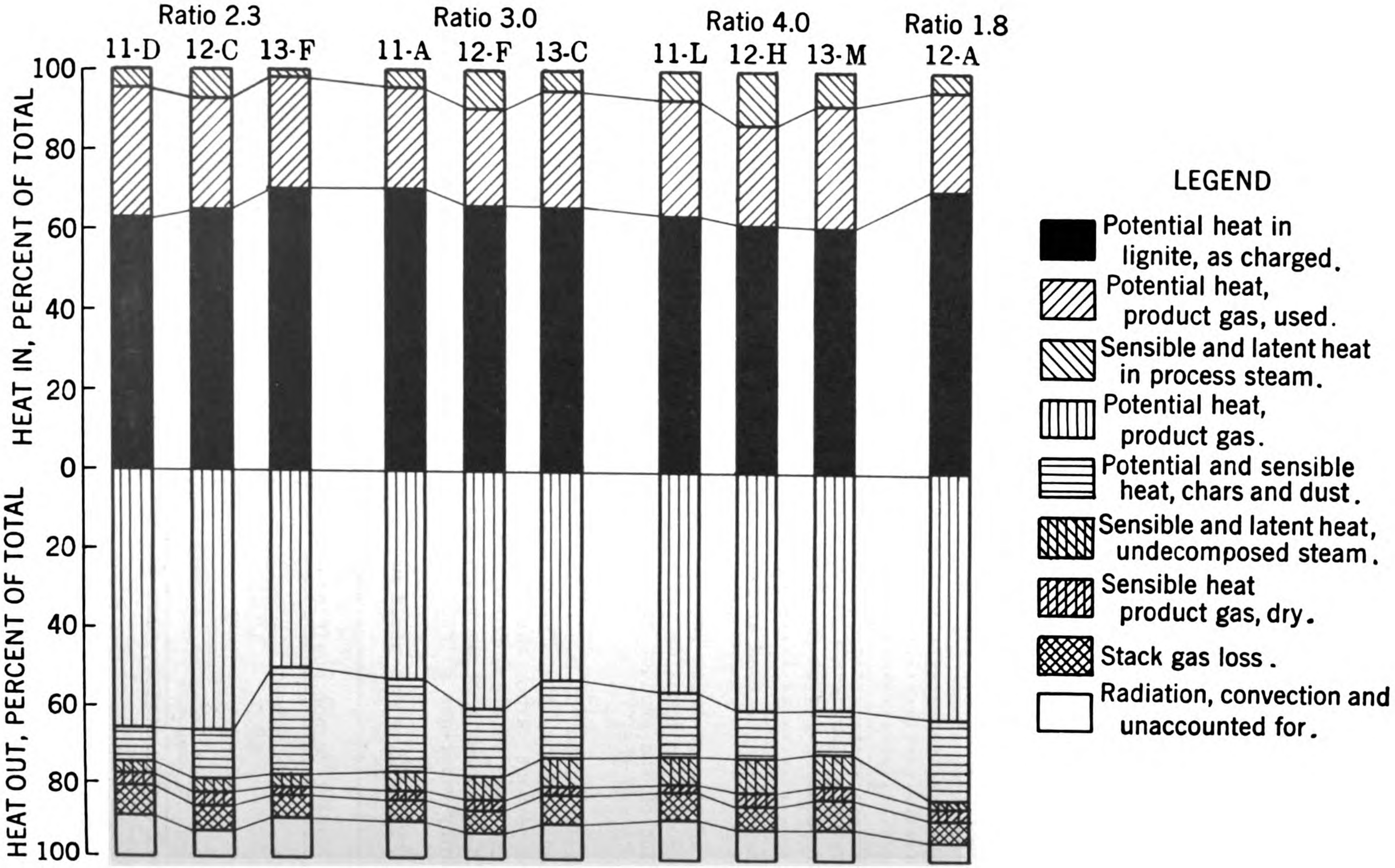

Figure 25. - Heat distribution during gasification of lignite in an externally heated retort at various hydrogen-carbon monoxide ratios, Bureau of Mines, Grand Forks, N. Dak.

in the product gas was between 49.1 and 65.5 percent of the total heat input. Adding potential heat in char and dust to that in the gas increased the percentage of total heat input recovered in the products to between 71.8 and 83.6 percent.

The service life of the externally heated alloy metal reaction tube was of primary importance because of its relatively high initial cost. Of four reaction tubes tested, a 310-alloy, rolled-plate tube gave the most promise of satisfactory life, as far as corrosion was concerned. After 1,862 hours of operation, the major portion of the inner surface of the tube exhibited little corrosion and the outer surface was in excellent condition, and although some deformation had occurred, it was not enough to affect operation.

Thermal requirements for the gasification of lignite in the externally heated retort were correlated in terms of undecomposed steam and the hydrogen-carbon monoxide ratio.[10] Heat requirements per standard cubic foot of wet gas, where wet gas is defined as the sum of noncondensable gases and undecomposed steam, varied widely with the hydrogen-carbon monoxide ratio. In contrast, the heat requirement per standard cubic foot of dry gas produced varied only moderately with the hydrogen-carbon monoxide ratio. Based on net heating value of the heating gas, the B.t.u. required per standard cubic foot of dry gas produced from natural lignite ranged from 135 to 107 between the H_2-CO ratios of 2 and 9. For gas produced from steam-dried lignite, this variation was from 110 to 96 between the ratios of 2 and 4. Therefore, it was concluded that in spite of the wide variations in the experimental conditions for gasifying lignite, the thermal requirements, on a basis of the volume of dry gas produced, were fixed within narrow limits.

Underground Gasification

From 1946 to 1953, field-scale experiments were made at Gorgas, Ala., on underground gasification of coal to develop a low-cost process for producing chemicals (from synthesis gas), heat, or power,[11][12] with the thought that such a process might utilize low-grade coal, coal in beds that are not easily accessible, or coal in pillars and barriers remaining in mined areas. The need for preliminary underground mining used in earlier trials was completely eliminated in the latest tests by developing the site by electrolinking, a method first developed in this country at the Missouri School of Mines. The composition and heating value of the product gas could be varied by using various gases for blowing: A undirectional air blast yielded lean producer gas; oxygen yielded a gas containing 195 B.t.u. per cubic foot, possibly suitable for synthesis gas; alternate air and steam operation yielded a variety of products, depending on the mode of operation. For example, water gas may be obtained with an average heating value of 279 B.t.u. per cubic foot, though volume produced was lower than when making producer gas with air blast. Improved operation reduced gas leakage from about 50 percent to 5 to 14 percent. With electrodes spaced 150 feet apart, 2,169 cubic feet per minute of 93-B.t.u. gas or 1,335 cubic feet per minute of 195-B.t.u. gas have been obtained, but there is no reason to believe that these yields could not be improved substantially. Variation of the quality of producer gas (air blast) decreased slowly with time of operation in a particular section, but this decrease was progressive with little fluctuation. The quality of the gas produced with oxygen appeared to fluctuate noticeably but may be amenable to closer control. Composition of the water gas varied with and during each cycle. A decrease in the loss of heat from the reaction zone should increase the efficiency of the operation considerably. These tests, which were developing the most promising data obtained to date on this project, were discontinued when appropriations for the work stopped.

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[10] Chetrick, M. H., Thermal Requirements for the Gasification of Lignite in an Externally-Heated Retort: Bureau of Mines Rept. of Investigations 4957, 1953, 7 pp.

[11] Elder, J. L., and Fies, M. H., Underground Gasification of Coal - the Gorgas Experiments: Consulting Eng., vol. 2, No. 6, August 1953, pp. 22-25, 62-64.

[12] Elder, J. L., and Fies, M. H., Untertagevergasung von Kohle: Brennstoff-Chem., vol. 34, No. 13/14, July 15, 1953, pp. 196-199.

RESEARCH ON PRODUCTION OF SYNTHESIS GAS

Kinetics of Gasification Reactions

In a related study to one on the kinetics of the reverse water-gas shift, previously reported, the reaction between methane and steam was studied in the temperature region 1,000° to 1,100° C., and at 1 atmosphere.[13] The reaction appeared to be a combination of the decomposition of methane followed by the steam-carbon reaction. Steam behaved as an inert gas until carbon was formed. Production of synthesis gas proceeded smoothly at 900° C., on a nickel catalyst; without an efficient catalyst, the reaction would be too slow to be practical.

Gasification of Coal

A bibliography of coal gasification was compiled[14] in preparation for a study of the kinetics of the gasification process.[15] A critical evaluation of the literature was made to determine the important reactions that occur during gasification. Equations were then developed that describe the rates of these reactions and take into account the changes in material composition and temperature as well as the rates of heat exchange and time of reaction. Agreement between calculated and experimental results was only fair, probably because of the simplifying assumptions that were necessary for making calculations.

A method has been described for combining coal hydrogenation in a fluidized system with gasification.[16] The residue from the hydrogenation step is low in sulfur and well suited for preparing synthesis gas.

More than 20 runs made with pulverized, Sewickley-bed coal in a down-flow gasification pilot plant[17] indicated the usefulness of gasification under pressure (see figs. 26 and 27).[18] After initial difficulties were overcome, large throughputs were obtained at pressures of 100, 250, and 300 p.s.i.g. At the highest pressure,

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[13] Gordon, A. S., The Reaction Between Methane and Steam in the Temperature Region, 1,000° to 1,100° C.: Ind. Eng. Chem., vol. 44, No. 8, 1952, pp. 1857-1859.

[14] Busche, R. M., Batchelder, H. R., and Armstrong, W. P., A Selected Bibliography of Coal Gasification: Bureau of Mines Rept. of Investigations 4926, 1952, 28 pp.

[15] Batchelder, H. R., Busche, R. M., and Armstrong, W. P., Kinetics of Coal Gasification: Ind. Eng. Chem., vol. 45, No. 9, 1953, pp. 1856-1878.

[16] Elliott, M. A., Clark, E. L., and Storch, H. H., Production of Hydrocarbon Synthesis Gas From Coal: United States Patent 2,634,286, Apr. 7, 1953.

[17] McGee, J. P., Schmidt, L. D., Danko, J. A., and Pears, C. D., Pressure-Gasification Pilot Plant Designed for Pulverized Coal and Oxygen at 30 Atmospheres: Chap. Gasification and Liquefaction of Coal, AIMME, New York, 1953, pp. 80-103.

[18] Strimbeck, G. R., Cordiner, J. B., Jr., Taylor, H. G., Plants, K. D., and Schmidt, L. D., Progress Report on Operation of Pressure-Gasification Pilot Plant Utilizing Pulverized Coal and Oxygen: Bureau of Mines Rept. of Investigations 4971, 1953, 27 pp.

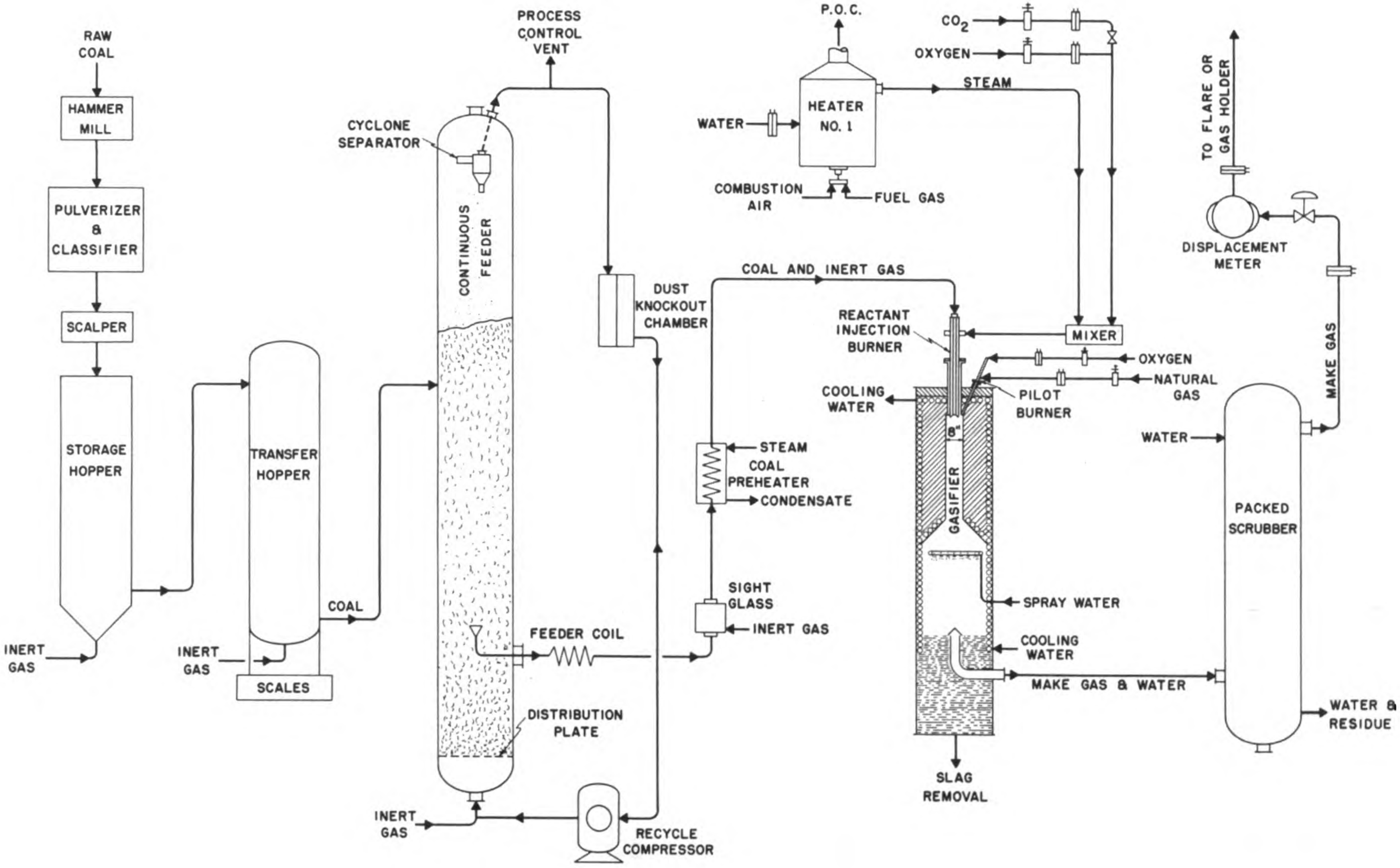

Figure 26. - Pilot-plant flowsheet for gasifier 3.

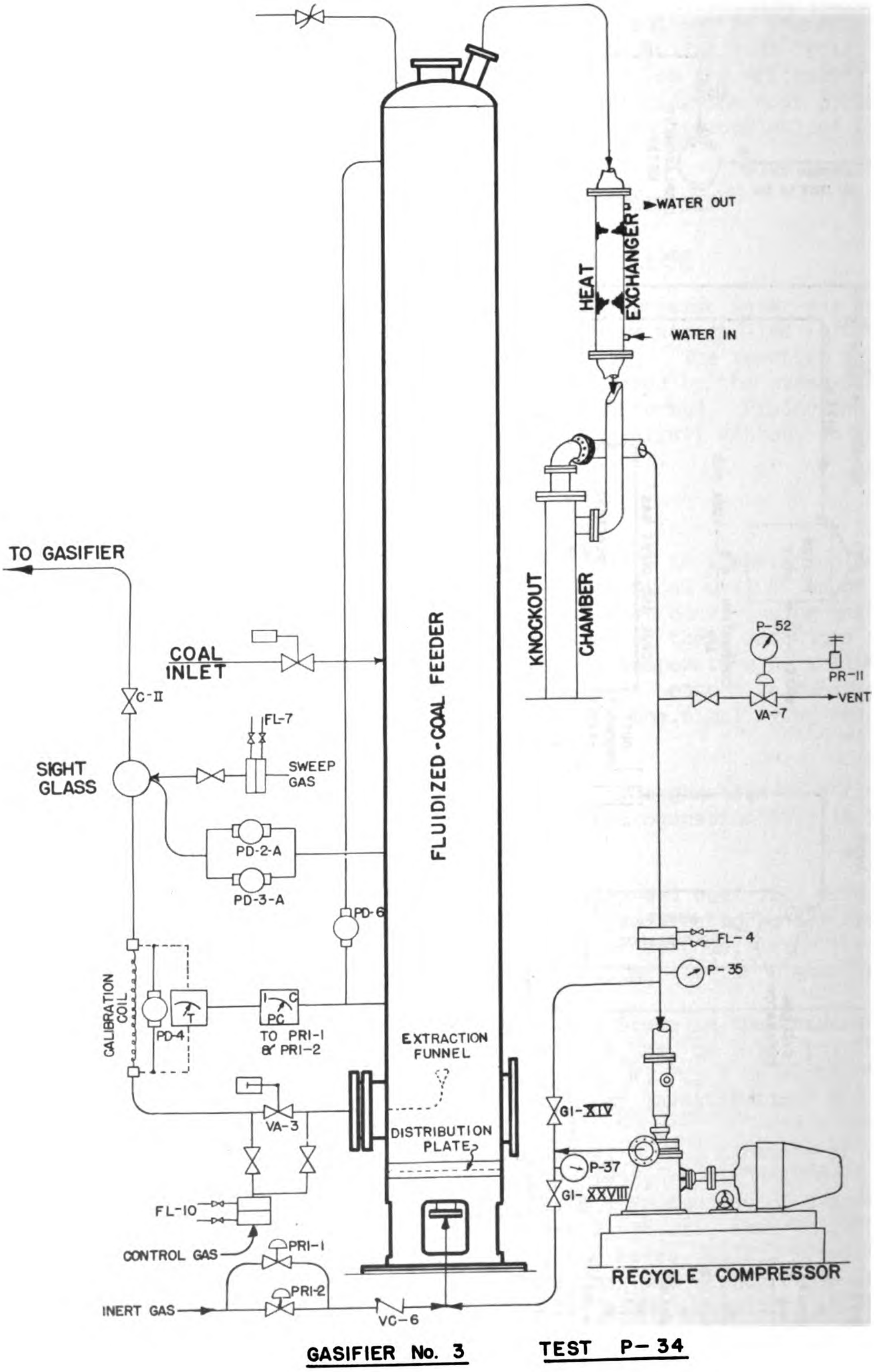

Figure 27. - Coal-feeder flowsheet.

500 pounds of coal per hour per cubic foot of gasifier volume were gasified; 350 cubic feet of oxygen and 35 pounds of coal were needed to make 1,000 cubic feet of synthesis gas. Comparatively small heat losses were observed. Operation under slagging conditions were possible, erosion of refractory lining was under control, and termination of tests was voluntary. Tests at higher pressure are in progress.

A study of the cost of producing synthesis gas for making ammonia showed that there are areas in the United States where gasification of coal is economical for this purpose.[19] Methods of making this and other types of synthesis gas have been reviewed,[20] with special emphasis on coal as the raw material.[21]

Purification of Synthesis Gas

One of the impurities in synthesis gas is hydrogen sulfide, and methods for its removal are being investigated. Solutions of tripotassium phosphate and glycine were used at 300 p.s.i.g. pressure in a pilot plant to remove hydrogen sulfide selectively from gases containing large amounts of carbon dioxide.[22] Neither the phosphate nor the glycine solution reduced the concentration of organic sulfur in the gas appreciably.

SYNTHETIC LIQUID FUELS BY GAS SYNTHESIS

Properties of Iron Catalysts

Pretreated and used iron Fischer-Tropsch catalysts were studied by electron and X-ray diffraction.[23] For precipitated catalysts that had been carbided or nitrided, the same phases were identified by both electron and X-ray diffraction. Fused or sintered catalysts that had been nitrided showed diffraction patterns of iron nitrides, but carburized samples produced electron diffraction patterns of magnetite or structural promoters only, although X-ray patterns for the carbides were obtained. Used catalysts had to be extracted to remove wax before electron diffraction patterns of magnetite and promoters were obtained; only some nitrided samples gave electron patterns of hexagonal iron carbonitride. In all cases, the electron diffraction patterns were less complete than the X-ray patterns.

The lack of diffraction lines of iron carbide in electron diffraction patterns of used catalysts, predominantly carbidic according to X-ray diffraction, indicates that no well-defined crystallites of carbide remain on the surface that is oxidized during synthesis. This observation further weakens the theory that iron carbide is an intermediate in gas synthesis.

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[19] Skinner, L. C., Batchelder, H. R., and Katell, S., Comparative Cost Study of Ammonia Plants: Ind. Eng. Chem., vol. 44, No. 10, October 1952, pp. 2381-2385.

[20] Newman, L. L., Trends in Gas Manufacture: Chap. in Gasification and Liquefaction of Coal, AIMME, New York, 1953, pp. 173-188.

[21] Schroeder, W. C., Significance of Process for Direct Gasification of Coal: Chap. in Gasification and Liquefaction of Coal, AIMME, New York, 1953, pp. 213, 214.

[22] Wainwright, H. W., Egleson, G. C., Brock, C. M., Fisher, J., and Sands, A. E., Selective Absorption of Hydrogen Sulfide From Synthesis Gas: Ind. Eng. Chem., vol. 45, No. 6, June 1953, pp. 1378-1384.

[23] McCartney, J. T., Hofer, L. J. E., Seligman, Bernard, Lecky, J. A., Peebles, W. C., and Anderson, R. B., Electron and X-Ray Diffraction Studies of Iron Fischer-Tropsch Catalysts: Jour. Phys. Chem., vol. 57, No. 7, October 1953, pp. 730-736.

Measurements of surface areas and pore volumes were used to follow the structural changes of fused iron oxide during treatments that may be used to condition it for gas synthesis.[24] Upon complete reduction at 450° to 550° C., such a catalyst develops an extensive pore structure corresponding to about 45 percent porosity. On reoxidation, the volumes of the individual particles remain constant, whereas the surface areas and pore volumes decrease. Reoxidation proceeds at a rapid rate initially, then becomes very slow after a few hours at the same temperature. Subsequently re-reduction is much easier than initial reduction. Formation of interstitial carbides and nitrides causes the catalyst particles to expand and the pore volume and diameters to increase. The percent porosity, however, remains about constant.

To determine whether thermal reactions might cause carbon deposition on Fischer-Tropsch catalysts, the transition from hexagonal close-packed iron carbide to Hägg iron carbide and the reaction of higher iron carbide with metallic iron to form cementite were studied in a copper- and alkali-promoted, precipitated iron catalyst using a magnetic balance (see fig. 28.)[25] The results show that, unless hexagonal iron carbide contains more carbon than Hägg iron carbide, deposition of carbon on iron catalysts during synthesis is not due to thermal reactions of iron carbides.

Similar techniques were used for following changes of iron catalysts during the early stages of carburization.[26] Carburization (up to 25 percent of carbide) of iron at 190° to 350° C. for short periods showed that hexagonal iron carbide may be the only carbidic phase up to 250° C. and is formed at temperatures as high as 325° C. The data explain why the hexagonal iron carbide is rarely found in fully carburized catalysts, even though it is the carbide that is formed first over a relatively wide range of temperatures. It was shown that the units and defining equations of magnetic susceptibility and specific magnetization - constants used to characterize chemical elements and compounds - can be chosen so that they are identical in the 3- and 4-dimensional c.g.s. systems.[27]

The preparation and reactions of carbonitrides of iron were studied at 250° to 450° C.[28] Two reactions occur when nitrides are treated with carbon monoxide or carbides with ammonia: A rapid completion reaction in which carbon or nitrogen enters the lattice interstitially until the ratio of interstitial to iron atoms has reached about 0.5, followed by a slower substitution reaction in which carbon replaces nitrogen or vice versa. When iron nitrides are treated with synthesis gas, the rate of elimination of nitrogen from the catalyst increases with higher hydrogen content of the gas; the rate of incorporation of carbon is maximum when about equal amounts of hydrogen and carbon monoxide are present. Nitrides are reduced rapidly

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[24] Hall, W. K., Tarn, W. H., and Anderson, R. B., Studies of the Fischer-Tropsch Synthesis, XIII.: Jour. Phys. Chem., vol. 56, No. 6, June 1952, pp. 688-691.

[25] Cohn, E. M., and Hofer, L. J. E., Some Thermal Reactions of the Higher Iron Carbides: Jour. Chem. Phys., vol. 21, No. 2, February 1953, pp. 354-359.

[26] Manes, M., Damick, A. D., Mentser, M., Cohn, E. M., and Hofer, L. J. E., Hexagonal Iron Carbide as an Intermediate in the Carbiding of Iron Fischer-Tropsch Catalysts: Jour. Am. Chem. Soc., vol. 74, No. 24, Dec. 20, 1952, pp. 6207-6209.

[27] Cohn, E. M., and Mentser, M., The c.g.s. Units of Magnetic Susceptibility and Specific Magnetization: Am. Jour. Physics, vol. 21, No. 9, December 1953, pp. 681-682.

[28] Hall, W. K., Dieter, W. E., Hofer, L. J. E., and Anderson, R. B., Preparation and Reactions of Carbonitrides of Iron: Jour. Am. Chem. Soc., vol. 75, No. 6, Mar. 20, 1953, pp. 1442-1447.

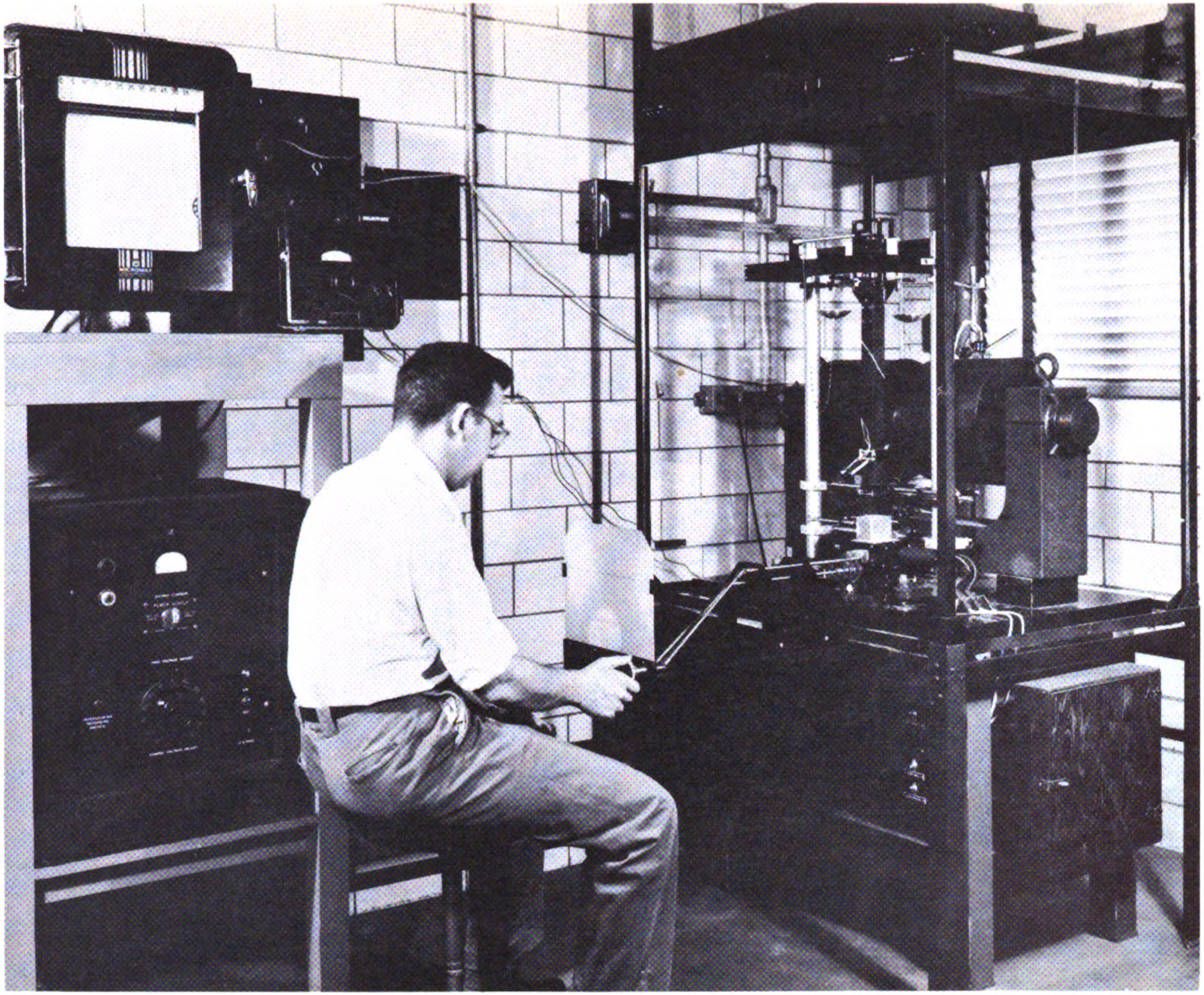

Figure 28. - Magnetic balance for thermomagnetic analysis of catalysts.

by pure hydrogen. Carbonitrides are reduced more slowly, the rate varying inversely with the carbon content; nitrogen is removed more rapidly than carbon, and the residual interstitial carbon appears as carbide.

Synthesis with Iron Catalysts

In a patent concerning the Fischer-Tropsch synthesis, a substantial improvement of the usage ratio (hydrogen to carbon monoxide) of the synthesis gas is claimed to be effected by passing fresh and recycled, dry (less than 1 volume-percent of water) synthesis gas, before use for synthesis, countercurrently to the cooling oil used in internally cooled converters.29/ As a consequence, the gas can be utilized more efficiently, a high rate of recycling is avoided, lower synthesis temperatures become possible, the concentration of organic acids is reduced, and the life of the catalyst is extended. These advantages are probably due, in part, to the removal of water from the cooling oil, and saturation of the oil with synthesis gas. As a result, the water-gas shift appears to be partly suppressed, and the concentration of carbon dioxide in the cooling oil is reduced. A pilot plant for removing carbon dioxide from synthesis gas is shown in figure 29.

Considerably more work has been done with iron nitrides and carbonitrides, the properties of which are described above.30/31/ The selectivity of such catalysts differs markedly from that of reduced, carbided, or inducted catalysts, the (carbo) nitrides yielding a product of lower average molecular weight containing a high percentage of oxygenated organic molecules. The yield from iron (carbo) nitride is usually at least equal to, and in most cases much higher than, that from nonnitrided iron. However, the intrinsic activity of a nitrided iron catalyst need not necessarily be higher than that of other iron catalysts, because the average molecular weight and size of the product may largely determine the amount of catalytic surface available for reaction.

For low space velocities of synthesis gas, the products obtained with nitrided iron catalysts in bench-scale reactors are somewhat similar to those made in the synol process at high space velocities and low temperatures. Perhaps even greater yields of oxygenates might be obtained with nitrided iron under synol conditions.

The various known processes for making alcohols, conditions of the synthesis, and properties of the products have been compared.32/ The synthesis of alcohols over metal oxides yields branched-chain products, whereas variants of the Fischer-Tropsch process yield chiefly primary, straight-chain alcohols. The mechanisms of chain growth appear to be different in the two types of synthesis.

29/ Crowell, J. H., and Benson, H. E., Catalytic Conversion of carbon Monoxide and Hydrogen to Hydrocarbons and Oxygenated Organic Compounds: United States Patent 2,617,816, Nov. 11, 1952.

30/ Anderson, R. B., Iron Nitrides as Fischer-Tropsch Catalysts: Chap. in Advance in Catalysis, vol. 5, Academic Press, 1953, pp. 355-384.

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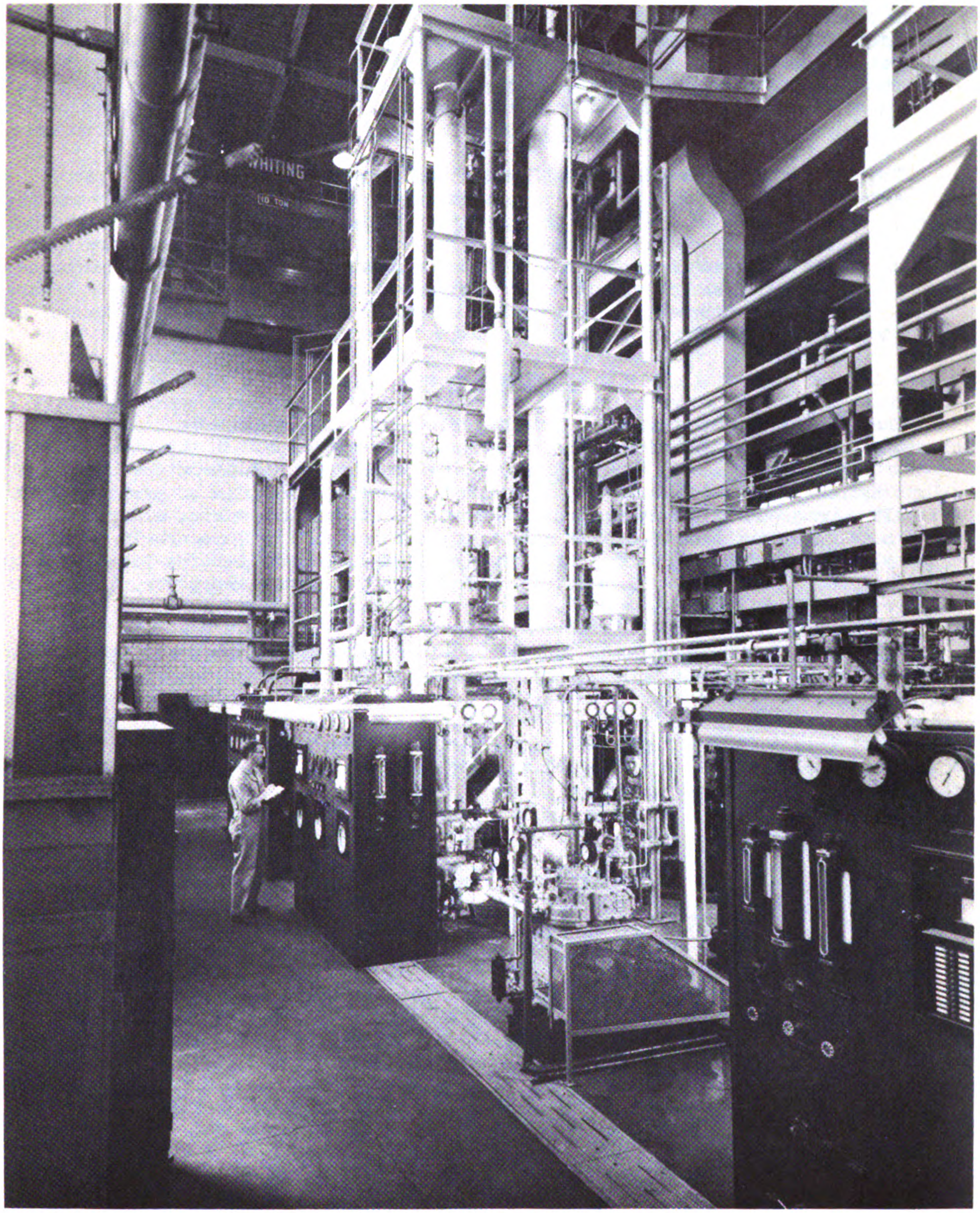

Figure 29. - Pilot plant for removing carbon dioxide from synthesis gas.

Feed-Rate Control

To introduce small amounts of liquids at known rates into bench-scale reactors for the gas synthesis, a feed system has been devised in which the mercury in a manometer acts as a piston for displacing the liquid.[33]

Gas-Synthesis Demonstration Plant

The Gas-Synthesis Demonstration Plant at Louisiana, Mo., has been described, and performance and process changes have been explained stepwise from oxygen manufacture and gasification of coal through synthesis and refining of products, including a short description of catalyst preparation.[34] Major items of equipment have been discussed with emphasis on mechanical design features. This and the coal-hydrogenation plant at Louisiana and results of operation of both demonstration plants have been discussed.[35] Operation of this plant was discontinued in June 1953, owing to reduction in appropriations.

The Oxo Reaction

The reaction of synthesis gas with a variety of types of organic compounds at elevated temperatures and pressures is conveniently carried out in the presence of a cobalt catalyst. A greatly improved method for preparing dicobalt octacarbonyl and cobalt hydrocarbonyl was developed.[36] In this reaction, a complex of pyridine with dicobalt octacarbonyl is formed, and addition of that salt to excess, dilute sulfuric acid in a stream of inert gas gives 95 percent yields of pure cobalt hydrocarbonyl. The hydrocarbonyl is stable in aqueous solution and behaves like a strong mineral acid; it decomposes in a solution of hexane and in the gas phase. Its infrared- and mass-spectrometric characteristics were determined.

The reaction between dicobalt octacarbonyl and dimethylamine proceeds at or below room temperature and at atmospheric pressure.[37] No carbon monoxide is evolved, and equimolar amounts of cobalt cation and cobalt carbonyl anion are formed. On the other hand, at 200° to 220° C. under 3,000 p.s.i.g. pressure of carbon monoxide, dimethylamine yields dimethylformamide in the presence of only 1 mole-percent of dicobalt octacarbonyl. Experiments with meta- and para-substituted benzyl alcohols showed that the rate of reaction decreases in the order

$$\text{p-OCH}_3 >> \text{p-CH}_3 > \left(\begin{matrix}\text{m-CH}_3\\ \text{p-tert.butyl}\end{matrix}\right) > \text{H} > \text{p-Cl} > \text{n-OCH}_3 >> \text{n-CF}_3.$$ [38]

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Under equal conditions, the quantity of homologation product increases over that of reduction product in the order in which the substituent promotes the release of electrons, but this effect is not as pronounced as the effect on reaction rate. Further evidence was obtained in support of the hypothesis that cobalt hydrocarbonyl is the hydroformylation catalyst.[39] A process was patented for reducing certain classes of aldehydes and ketones to the corresponding alcohols under hydroformylation conditions.[40]

SYNTHETIC LIQUID FUELS BY COAL HYDROGENATION

Equipment for Hydrogenation of Coal

Many instrumentation problems encountered in high-pressure work cannot be solved with commercially obtainable implements. To satisfy these needs, a number of pieces of equipment have been developed at the coal-hydrogenation laboratories. These include various connectors for tubing; a sealing ring for autoclaves; a quick-opening product receiver; and a pump, back pressure regulator, and flow meter for small flows at high pressures.[41] An automatic, sensitive, pneumatic pressure controller has been developed for regulating the flow of hydrogen to a bench-scale, high-pressure hydrogenation unit.[42] It utilizes a 20-turn helical Bourdon tube that is connected to the flapper of a nozzle-flapper combination. When the nozzle is closed, air pressure in the controller acts through a system of bellows and cylinders on a rack, which drives a gear connected to the regulating valve. The controller prevents slow drifts of pressure and has operated satisfactorily at 9,000 p.s.i.g. pressure. The important factors in the design and maintenance of high-pressure pumps for pilot-plant work have been discussed, and the type of small pump used in the coal-hydrogenation laboratories has been illustrated and described.[43]

Corrosion and erosion during 2 years of intermittent operation of the coal-hydrogenation demonstration plant and solutions of these problems have been described.[44] Proper selection of alloy steels has minimized the effects of hydrogen on high-pressure equipment.

Problems in the continuous preparation of sized pulverized coal and of coal paste and its transfer to coal-hydrogenation reactors have been described.[45] These include drying, pulverizing, weighing, mixing, and pumping of paste at both low and high pressures. Some of this information and a summary of the results of operation of the demonstration plant were presented at a symposium.[46]

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Hydrogenation of Coal and Shale Oil

The use of a finely divided alloy of zinc and antimony in coal hydrogenation has been described.[47] Though less expensive and more readily available than tin, which it is intended to replace, the catalyst is not as effective as tin and has been superseded by later developments.[48]

Application of standard kinetic techniques has made possible the quantitative evaluation of the effectiveness of catalysts for the hydrogenation of coal.[49] The conversion of coal to asphaltenic materials is a first-order reaction with respect to benzene-insoluble substance remaining. Specific reaction rate constants can therefore be calculated, and these, when plotted as a function of hydrogenation pressure, yield straight lines, the slopes and intercepts of which are characteristic for the catalysts used with a given coal. For Rock Springs, Wyo., bituminous coal hydrogenated at 400° C., the relationship between specific reaction rate constant K (min.$^{-1}$) and initial hydrogen pressure P (p.s.i.g.) is:

$$K = 1.5 \times 10^{-5} P$$

in the presence of tin (1 percent, based on coal) as stannous sulfide and ammonium chloride (0.5 percent); and is

$$K = 1.5 \times 10^{-5} P + 0.0225$$

in the presence of molybdenum (1 percent) as ammonium molybdate. Thus, to obtain the same conversion of this coal under otherwise equal conditions, the initial pressure must be 1,500 p.s.i.g. higher with tin plus ammonium chloride than with molybdenum.

Five liquid-phase tests and one vapor-phase test in the Demonstration Plant have been reported.[50][51] Approximately 3,000 tons of Rock Springs, Wyo., coal and over 100,000 gallons of tar oils were processed to produce nearly 300,000 gallons of 78-octane (motor method) gasoline and oils. The net yield was 3.5 to 3.9 barrels of oils per ton of m.a.f. coal. The light oils made in the liquid-phase tests had a gross tar-acid content of 22.7 gallons per ton of m.a.f. coal, of which 11.3 gallons were phenol, cresols, and xylenols. The gross tar-base content was 4 gallons per ton. About 7 weight-percent of hydrogen, based on coal, was consumed during hydrogenation.

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During the vapor-phase operation, 1.08 gallons of gasoline were produced per gallon of feed (obtained from liquid-phase hydrogenation) at 875° F.; at 888° F., more feed was gasified and only 0.96 gallon of gasoline was recovered. About 4.2 weight-percent of hydrogen was consumed in this operation. The naphthene content of the product was high, making this an excellent stock for conversion to aromatics by standard petroleum refining techniques.

To evaluate the amenability to hydrogenation of oil derived from oil shale,52/ crude shale oil, obtained by treating Colorado shale in a gas-flow retort, was hydrogenated in the coal-hydrogenation pilot plant.53/ The product obtained at 800° to 900° F. and 9,000 p.s.i.g. of hydrogen in the presence of tungsten or cobalt molybdate catalyst is essentially free of sulfur and nitrogen and suitable for further processing by standard petroleum methods. Forty to fifty volume-percent of the treated oil is high-quality diesel fuel with cetane numbers ranging from 50 to 60. Consumption of hydrogen varied from 2,000 to 2,800 cubic feet per barrel of crude oil, depending upon the catalyst used.

Characterization of Coal and Products From Hydrogenation

The similarity of the infrared spectra of anthraxylon from bituminous coal and of chars from cellulose and sugar indicates the presence of definite molecular configurations in the chars and lends support to the hypothesis that cellulose is a precursor of coal.54/

Coronene has been identified as one of the constituents of the oil produced by hydrogenation of coal.55/ It was isolated from the high-boiling portion of the oil by codistillation with polypropylene glycol of average molecular weight 750. Its identity was established by comparing its ultraviolet spectrum and x-ray diffraction pattern with those of an authentic specimen. A small-angle X-ray diffraction camera (fig. 30) was designed and built for studying the structural properties of coal.

Analysis of a coal-hydrogenation oil produced at the demonstration plant at Louisiana, Mo., showed that it contained 11.15 percent of paraffins, 29.2 percent naphthenes, and 18.30 percent aromatics in the gasoline range.56/ The C_6 to C_8 fraction of such oils is an excellent source of benzene, toluene, and xylenes.

52/ For recent information on Bureau of Mines work on oil shale and shale oil, see Synthetic Liquid Fuels Annual Report of the Secretary of the Interior for 1952, Part 2, Oil From Oil Shale; Bureau of Mines Rept. of Investigations 4943, 1953, 70 pp.

53/ Pelipetz, M. G., Wolfson, M. L., Ginsberg, H., and Clark, E. L., High-Pressure Hydrogenation of Crude Shale Oil: Chem. Eng. Prog., vol. 48, No. 7, July 1952, pp. 353-356.

54/ Friedel, R. A., and Pelipetz, M. G., Infrared Spectra of Coal and Carbonhydrate Chars: Jour. Opt. Soc. America, vol. 43, 1953, p. 1051.

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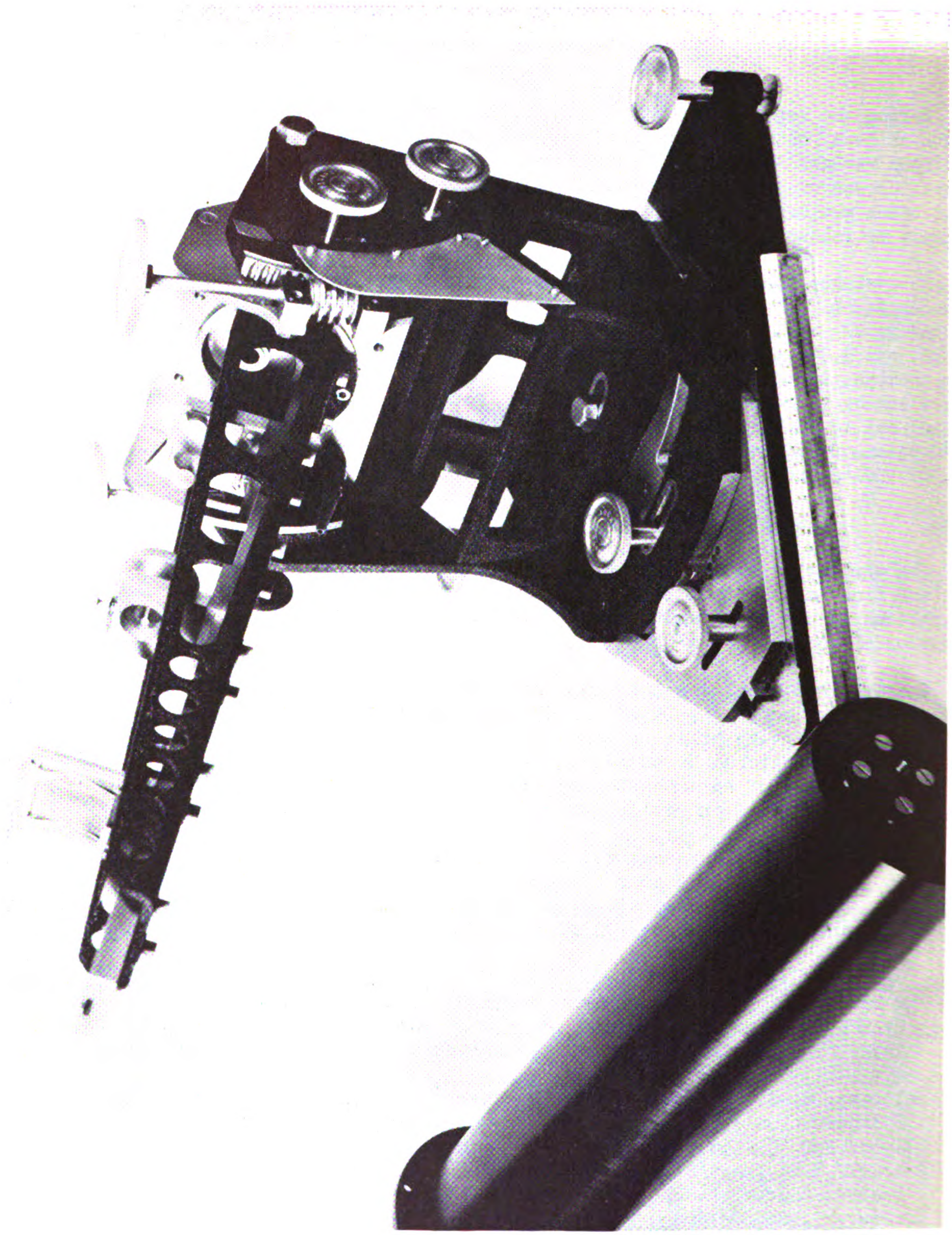

Figure 30. - Small-angle X-ray diffraction camera.

Bibliography of Pressure Hydrogenation

Appearance of the index to the Bibliography of Pressure hydrogenation completes publication of this compilation of more than 6,000 abstracts of papers and patents that have appeared in this field through 1948.[57]

ANALYTICAL TECHNIQUES FOR CHARACTERIZING PRODUCTS FROM GAS SYNTHESIS AND COAL HYDROGENATION

The oxygen content of organic chemicals is often determined by difference, so that all the analytical errors are contained in that value. This disadvantage is obviated by Unterzaucher's method of direct determination of oxygen. The apparatus and procedure have been improved to overcome interference from hydrogen and permit accurate and rapid analyses for a wide range of oxygen contents.[58] To avoid leakage through glass stopcocks in bench-scale apparatus, an improved method was developed for producing high-precision glass stopcocks.[59]

In the distillation laboratory, a method for evaluating vacuum rectification columns and removable packing supports for glass columns was developed.[60][61] Azeotropic distillation was used to separate the alpha- and beta-isomers of methylnaphthalene.[62] Optimum conditions were determined for separating nitromethane from nitroethane by distillation at subatmospheric pressure.[63]

Phenols are a valuable constituent of oil obtained by hydrogenation of coal.[64] The countercurrent extraction technique of separating these tar acids as well as tar bases was investigated with cresols, substituted anilines and pyridines, and isomers of toluidine and methylquinoline.[65][66][67]

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Mass spectrometric analysis has been applied to the characterization of mixtures similar to gasoline obtained from coal hydrogenation.[68] Mono- and polysubstituted cyclopentanes and cyclohexanes have thus been identified. In a cooperative project with the Explosives Division of the Bureau of Mines,the mass-spectrometric technique was applied to the analysis of gas mixtures containing nitrogen dioxide.[69]

Radioactive carbon is being used to identify compounds in synthetic fuels and to gain further insight into the course of the chemical reactions. (See fig. 31.)

SYNTHETIC LIQUID FUELS PUBLICATIONS

Recent developments in the field of catalysis have been reviewed.[70][71]

The present status of processes for producing synthetic liquid fuels and current problems in the physical chemistry of coal have been discussed.[72][73][74][75][76][77][78][79]

Vertical velocities of particles along a container wall were determined in fluidized sand and in silica-gel beds,[80] and the 1952 literature on fluid dynamics was reviewed.[81]

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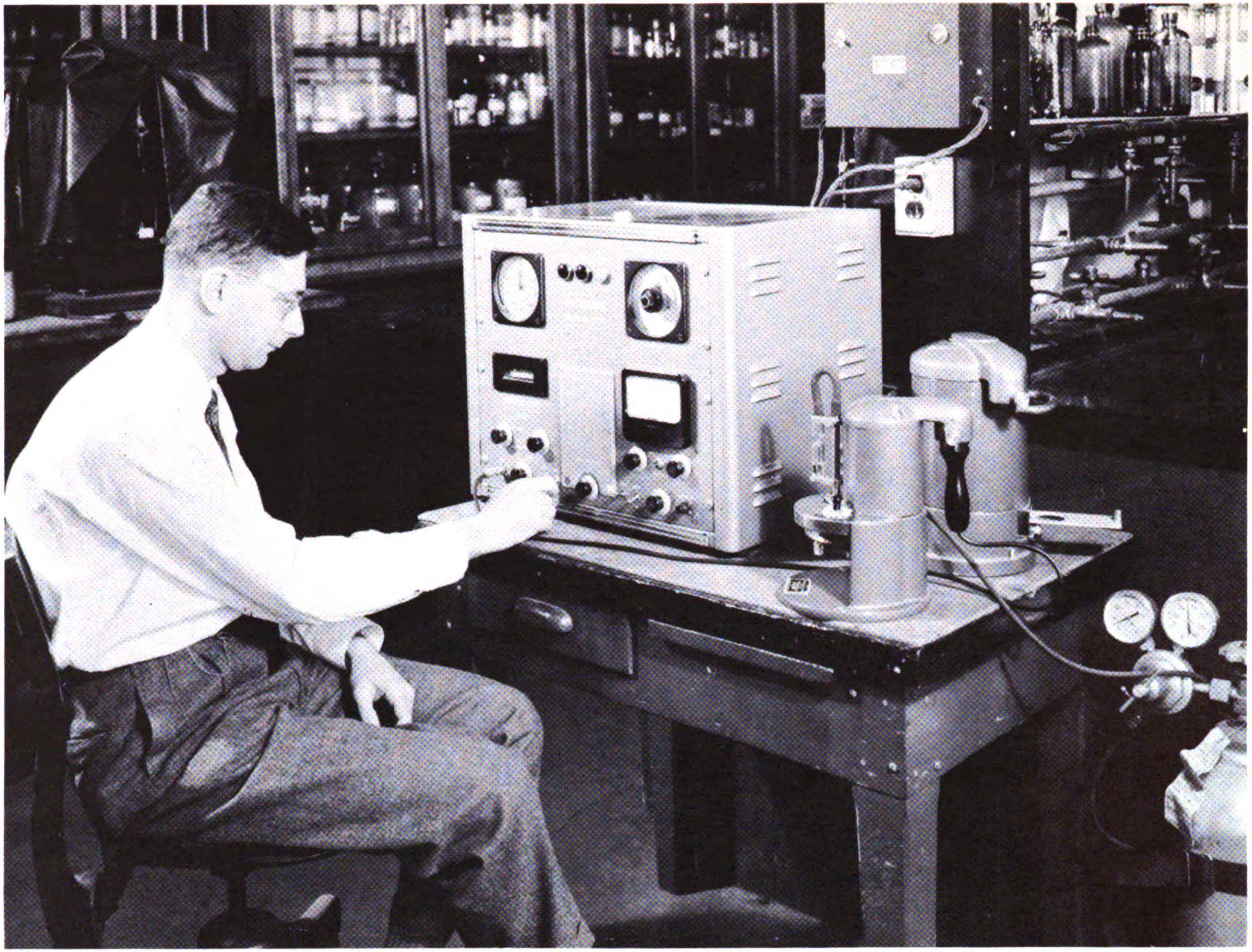

Figure 31. - Apparatus for measuring action of radioactive samples.

A theoretical study was made of the relaxation time of equilibrium systems as related to ultrasonic absorption and reaction kinetics.[82] [83]

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